Computers, brains and AI

3: Logic (silicon and computers)

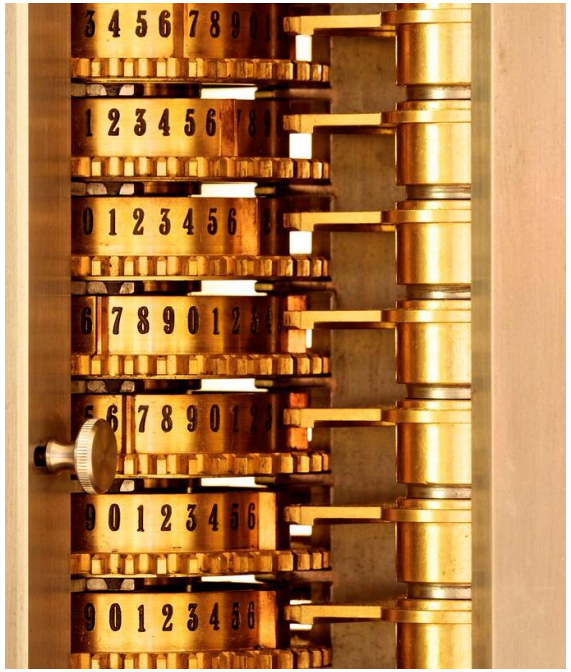


Photo by Marcin Wichary / CC BY
Photo by Science Museum Group / CC0

Today...

Silicon

Computers

1) Intro

2) Foundations

3) ~~Logic~~ Silicon

4) Deep learning

5) Deep learning

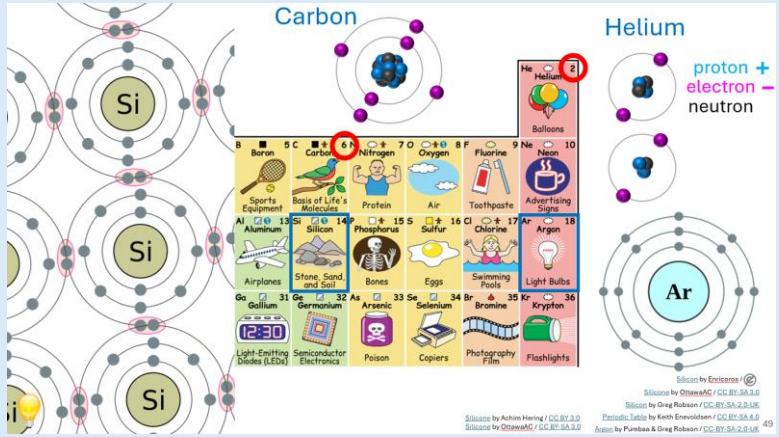
6) ChatGPT

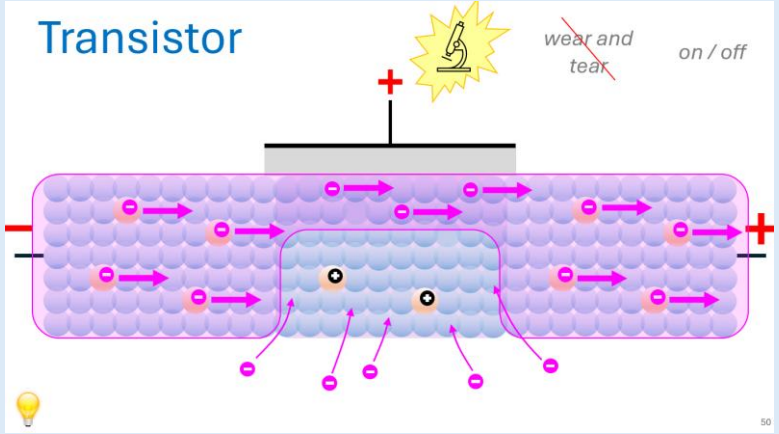
7) ChatGPT

8) ChatGPT

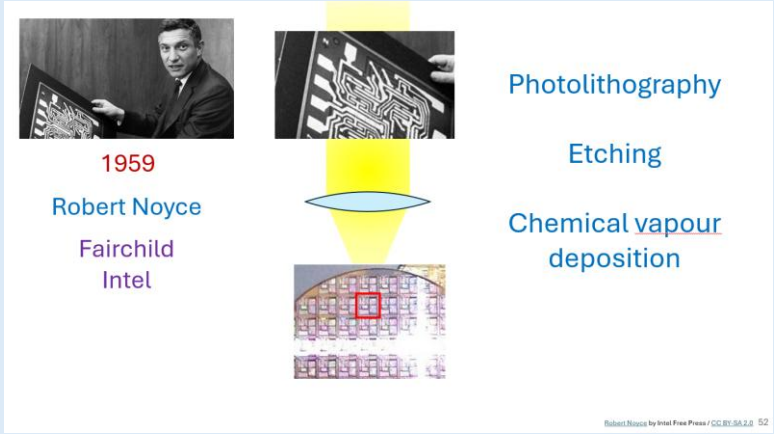
9) The future of AI

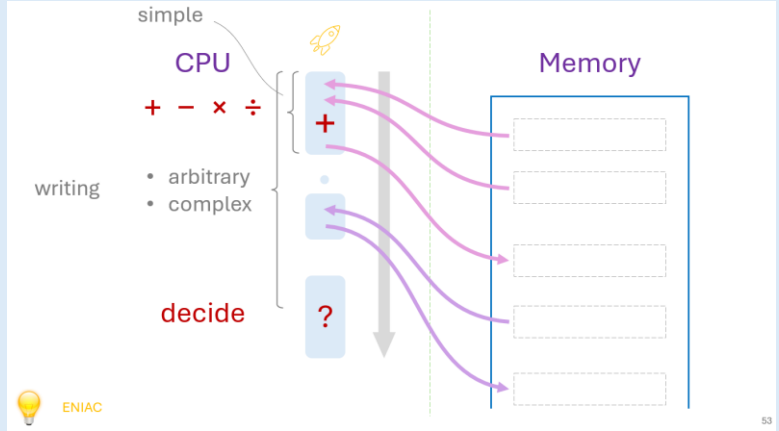
10) The future of AI

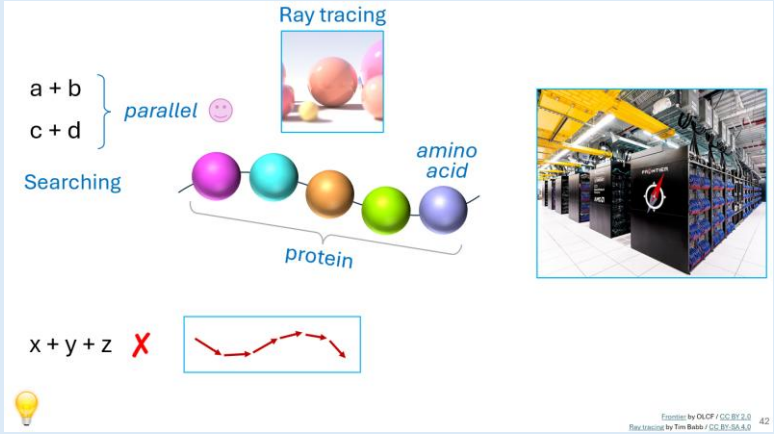

Carbon
Helium
proton +
electron −
neutron
Si
Si
Si
Ar
Boron
Carbon
Nitrogen
Oxygen
Fluorine
Neon
Helium
Aluminum
Silicon
Phosphorus
Sulfur
Chlorine
Argon
Gallium
Germanium
Arsenic
Selenium
Bromine
Krypton
Sports Equipment
Basis of Life's Molecules
Protein
Air
Toothpaste
Advertising Signs
Balloons
Airplanes
Stone, Sand, and Soil
Bones
Eggs
Swimming Pools
Light Bulbs
Light-Emitting Diodes (LEDs)
Semiconductor Electronics
Poison
Copiers
Photography Film
Flashlights


Transistor
wear and tear
on / off
+
−
+

Jan Czochralski
1915
sand
silicon
99.9999999%
quartz
1956
Czochralski process
crystal
Silicon ingot

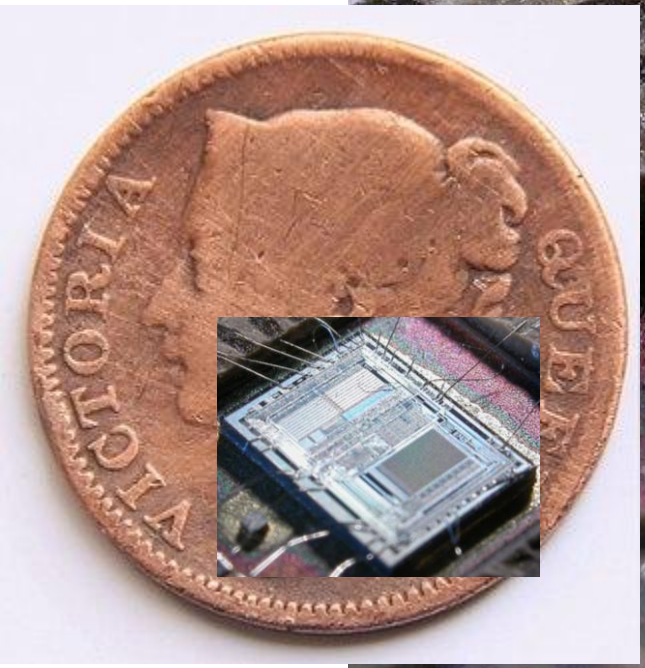

1959
Robert Noyce
Fairchild
Intel
Photolithography
Etching
Chemical vapour deposition

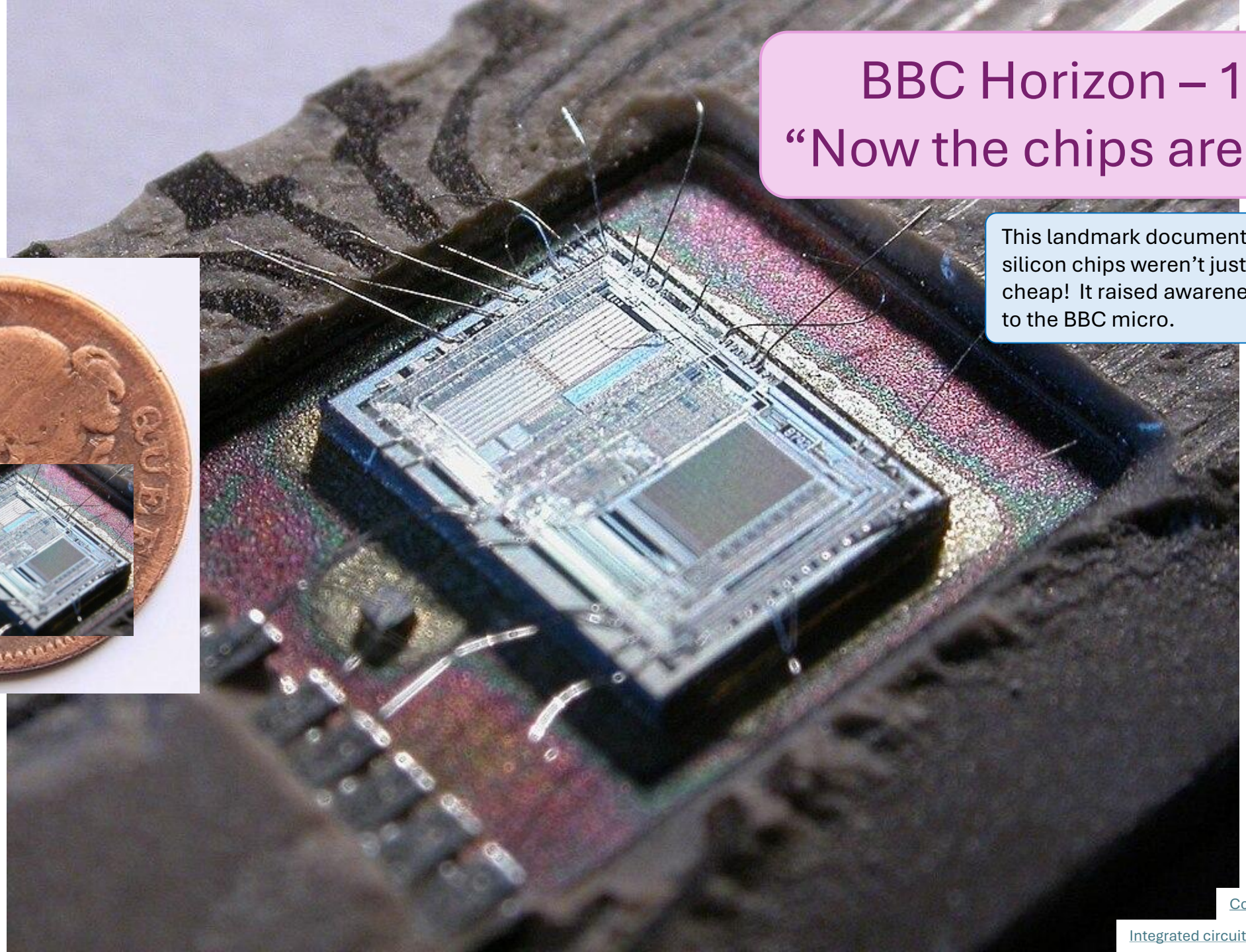

simple
CPU
+ − × ÷
writing
• arbitrary
• complex
decide
?
Memory
ENIAC


Ray tracing
a + b
c + d
parallel
Searching
amino acid
protein
x + y + z ✗

BBC Horizon – 1978
“Now the chips are down”

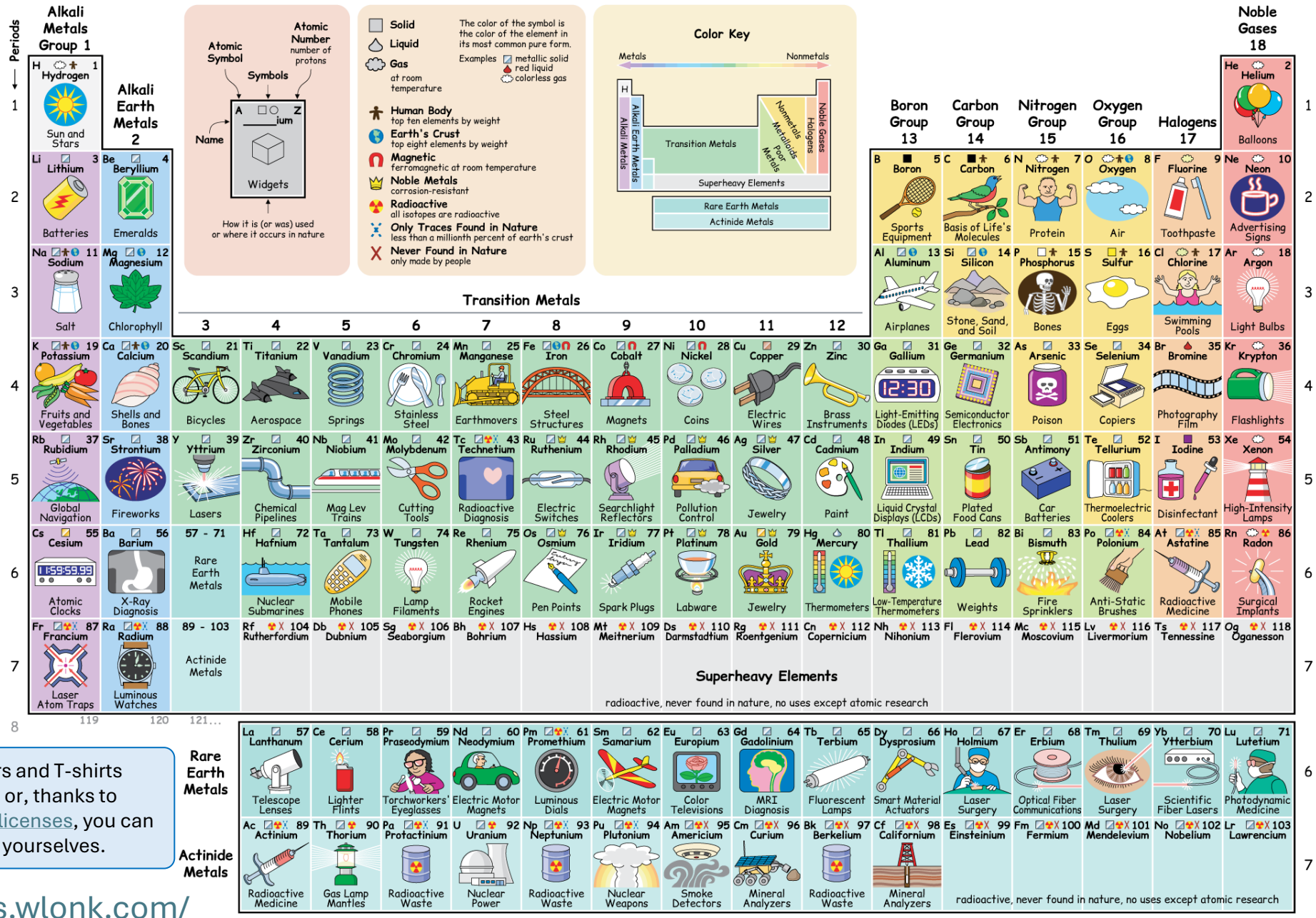
This landmark documentary pointed out that silicon chips weren’t just small – they were cheap! It raised awareness and helped lead to the BBC micro.





Coin By AKS.9955 / CC BY-SA 4.0
Integrated circuit by Ioan Sameli / CC BY-SA 2.0

The Periodic Table of the Elements, in Pictures



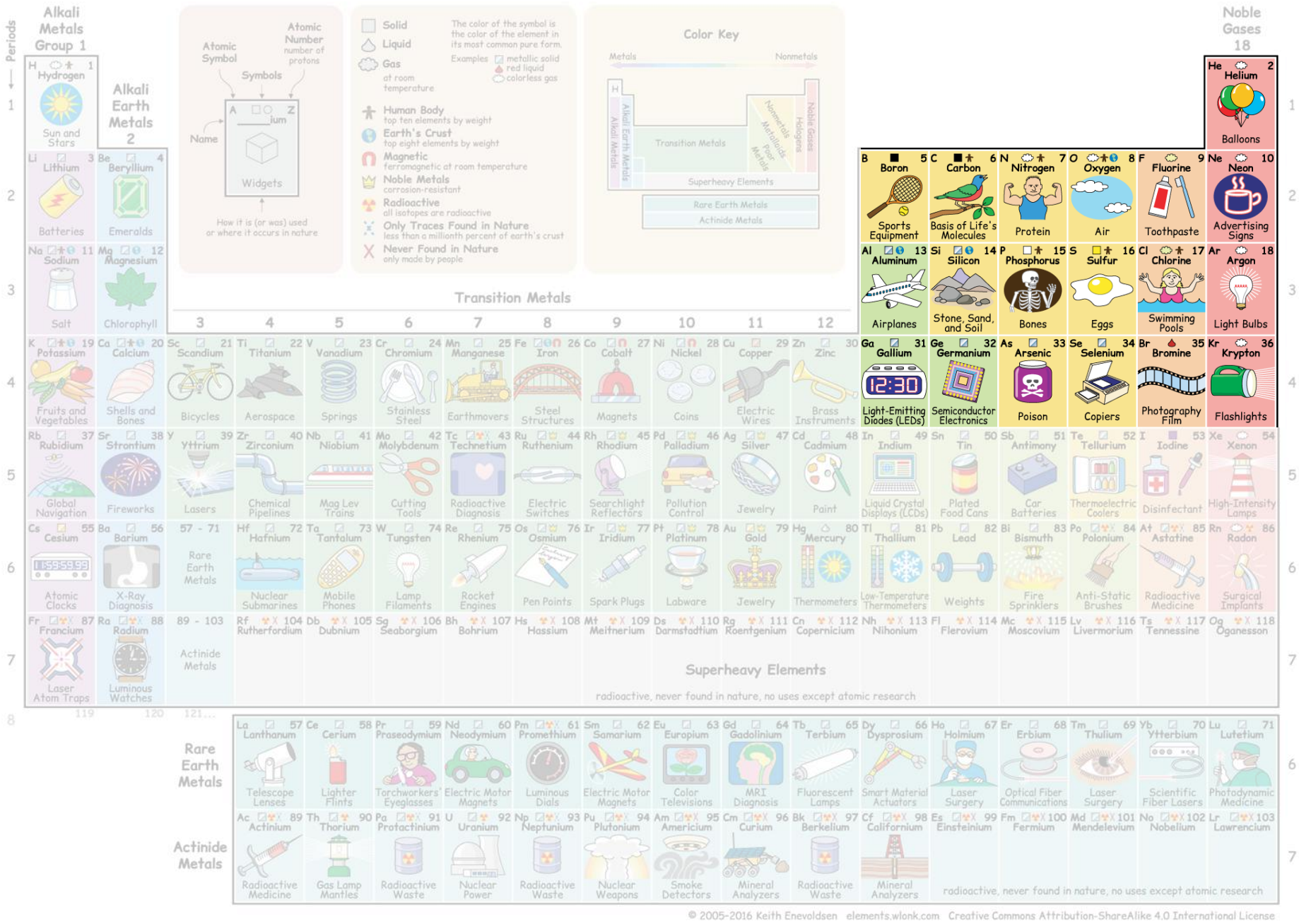
You can buy lovely posters and T-shirts from https://wlonk.com/, or, thanks to their Creative Commons licenses, you can download and print them yourselves.

https://elements.wlonk.com/

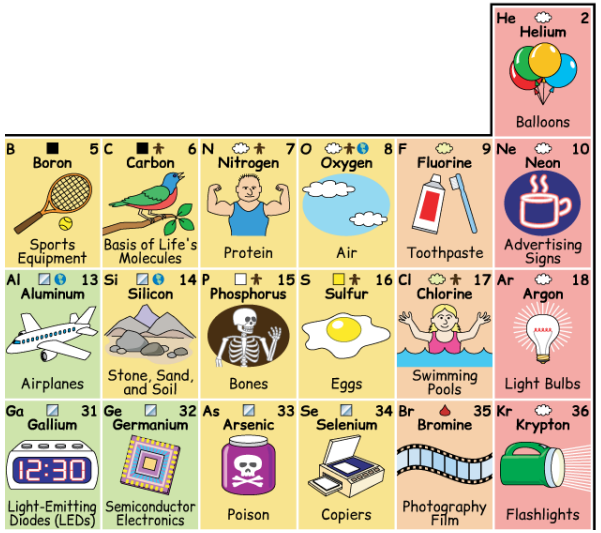
© 2005-2016 Keith Enevoldsen elements.wlonk.com Creative Commons Attribution-ShareAlike 4.0 International License

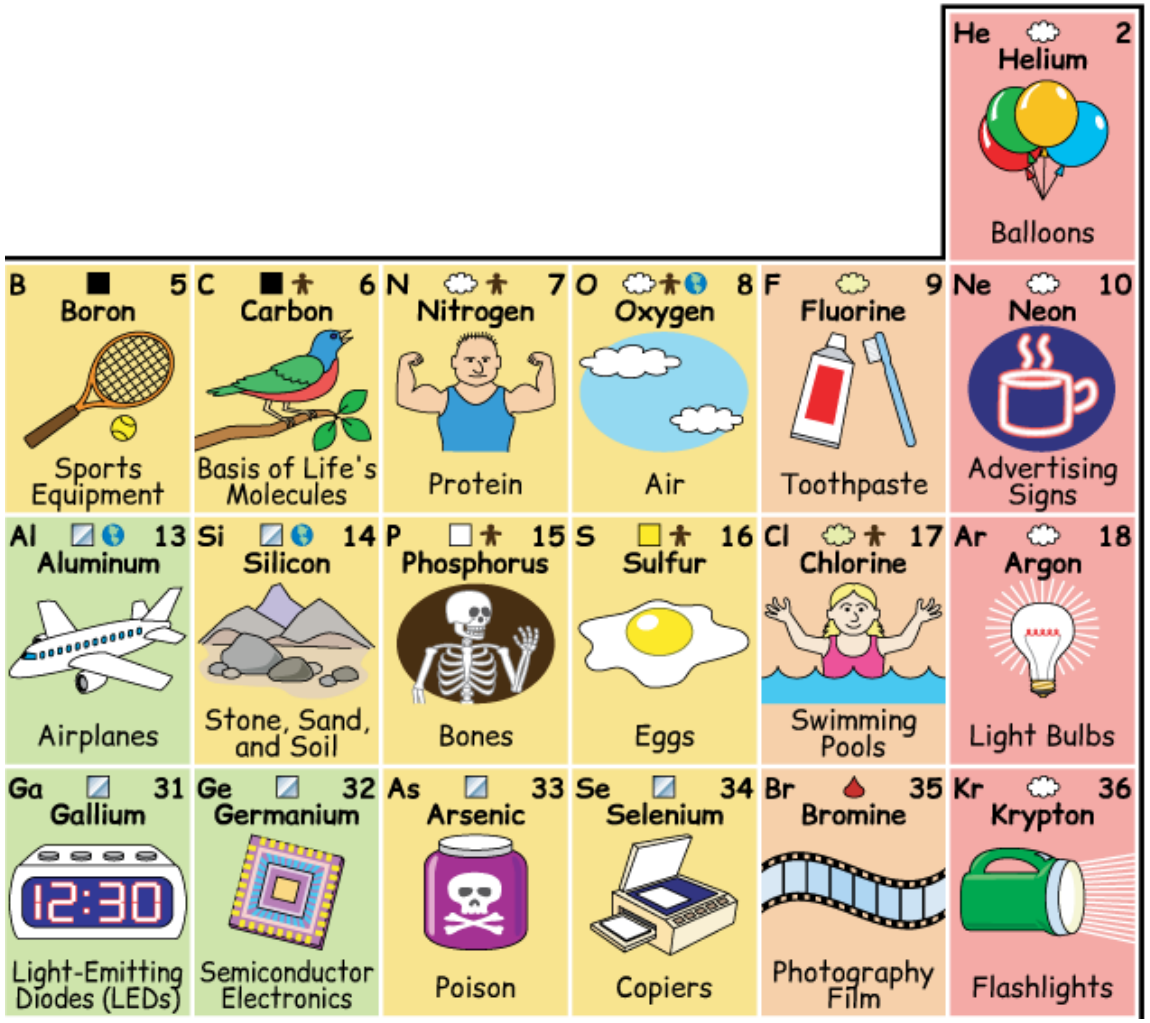
Periodic Table
by Keith Enevoldsen
CC BY-SA 4.0

The Periodic Table of the Elements, in Pictures



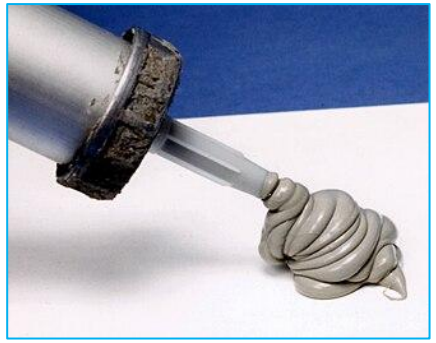
Periodic Table
by Keith Enevoldsen
CC BY-SA 4.0


He 2 Helium
Balloons
B 5 Boron
Sports Equipment
C 6 Carbon
Basis of Life's Molecules
N 7 Nitrogen
Protein
O 8 Oxygen
Air
F 9 Fluorine
Toothpaste
Ne 10 Neon
Advertising Signs
Al 13 Aluminum
Airplanes
Si 14 Silicon
Stone, Sand, and Soil
P 15 Phosphorus
Bones
S 16 Sulfur
Eggs
Cl 17 Chlorine
Swimming Pools
Ar 18 Argon
Light Bulbs
Ga 31 Gallium
12:30
Light-Emitting Diodes (LEDs)
Ge 32 Germanium
Semiconductor Electronics
As 33 Arsenic
Poison
Se 34 Selenium
Copiers
Br 35 Bromine
Photography Film
Kr 36 Krypton
Flashlights


He 2 Helium
Balloons
B 5 Boron
Sports Equipment
C 6 Carbon
Basis of Life's Molecules
N 7 Nitrogen
Protein
O 8 Oxygen
Air
F 9 Fluorine
Toothpaste
Ne 10 Neon
Advertising Signs
Al 13 Aluminum
Airplanes
Si 14 Silicon
Stone, Sand, and Soil
P 15 Phosphorus
Bones
S 16 Sulfur
Eggs
Cl 17 Chlorine
Swimming Pools
Ar 18 Argon
Light Bulbs
Ga 31 Gallium
12:30
Light-Emitting Diodes (LEDs)
Ge 32 Germanium
Semiconductor Electronics
As 33 Arsenic
Poison
Se 34 Selenium
Copiers
Br 35 Bromine
Photography Film
Kr 36 Krypton
Flashlights

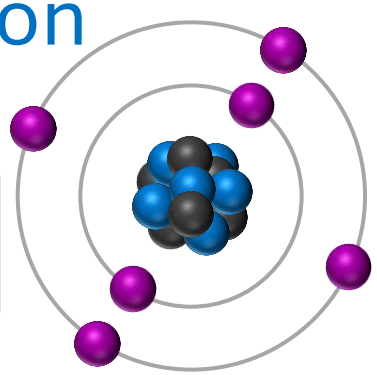
Silicon

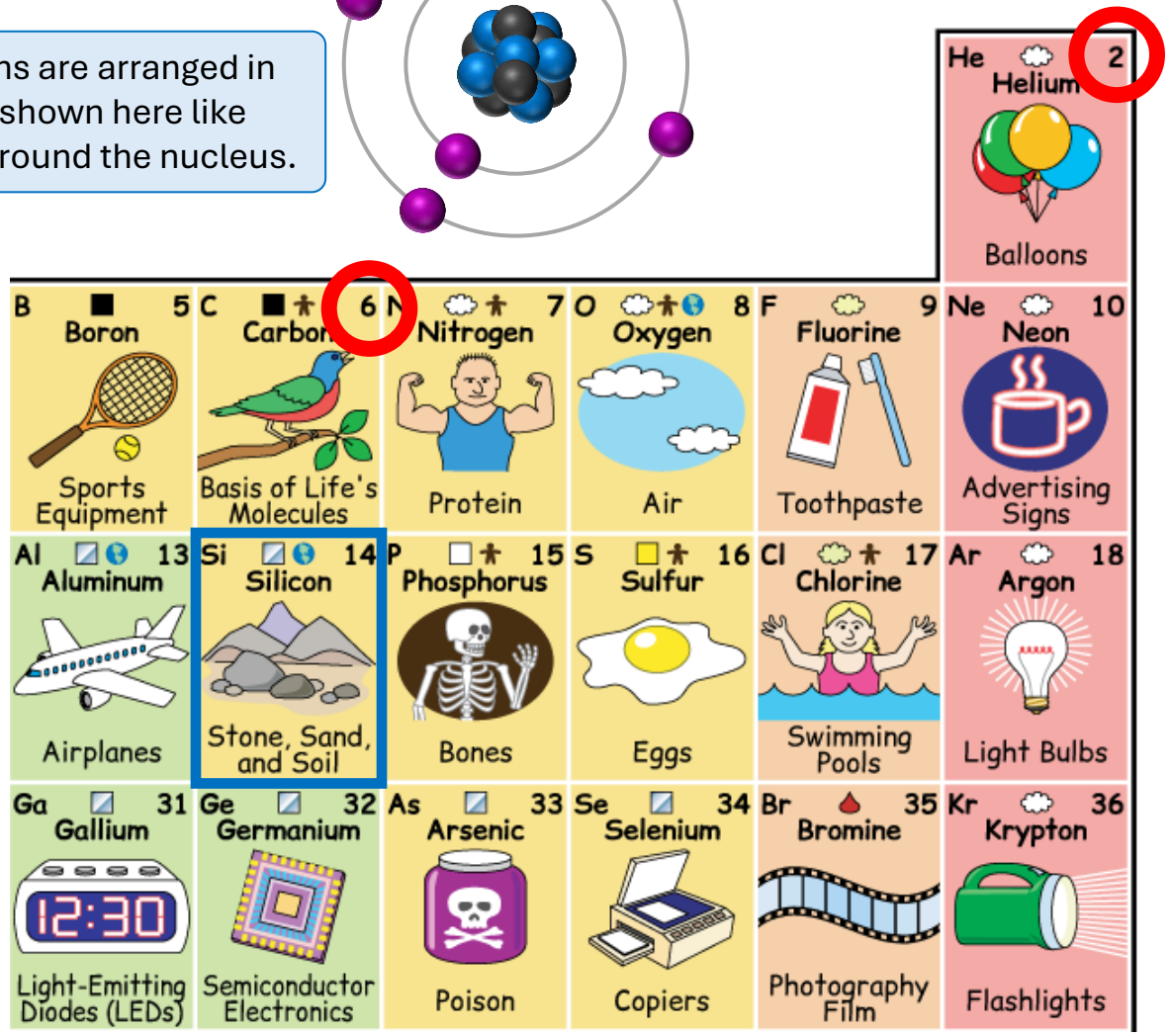
Silicone



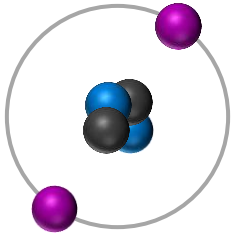
Carbon

Electrons are arranged in **shells**, shown here like orbits around the nucleus.

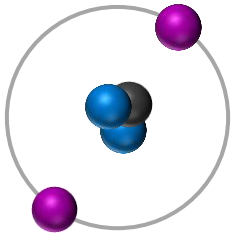




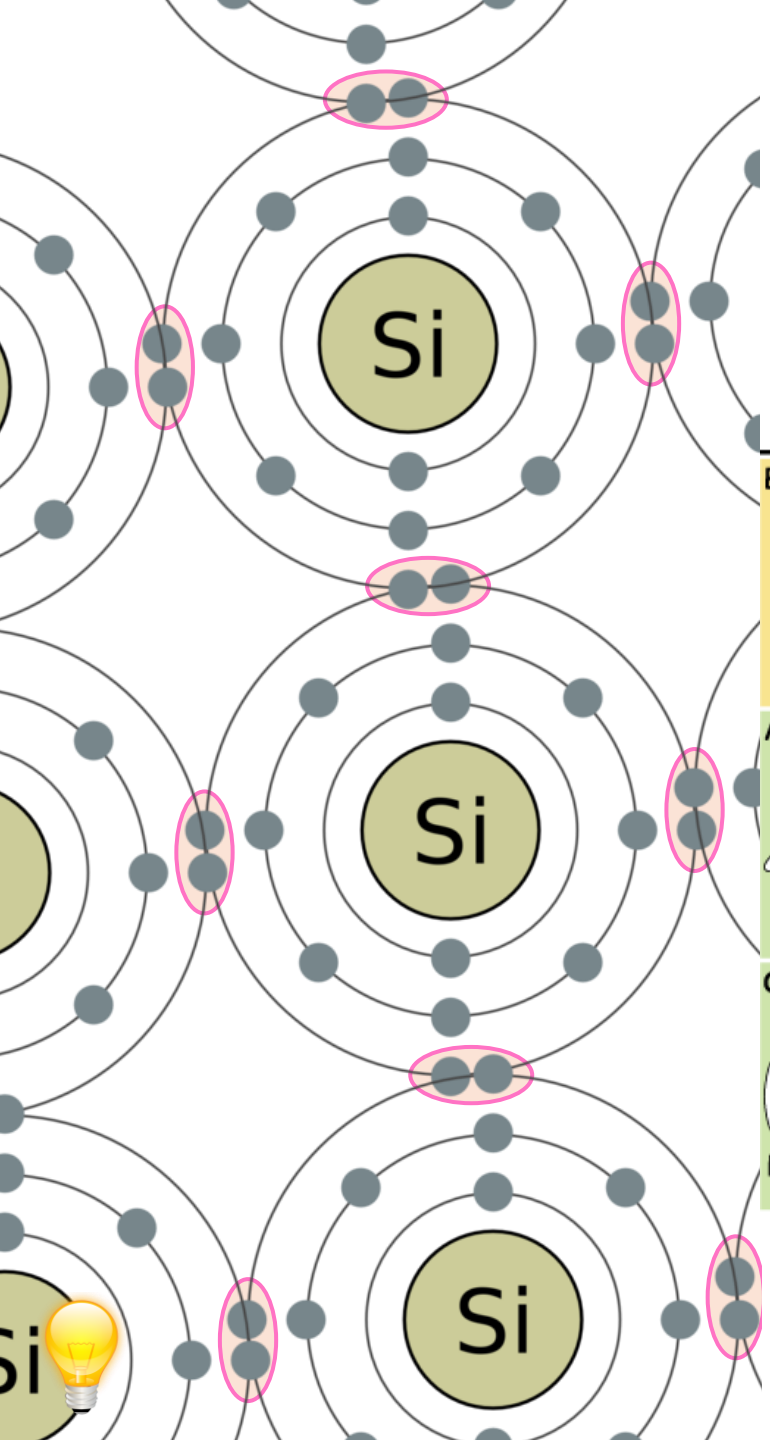
Helium



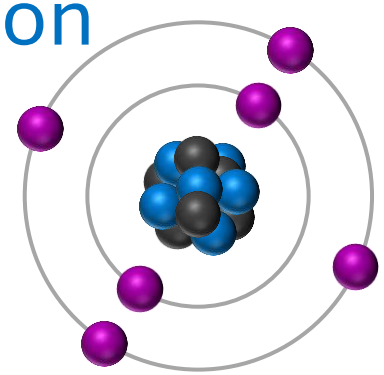
proton +
electron –
neutron

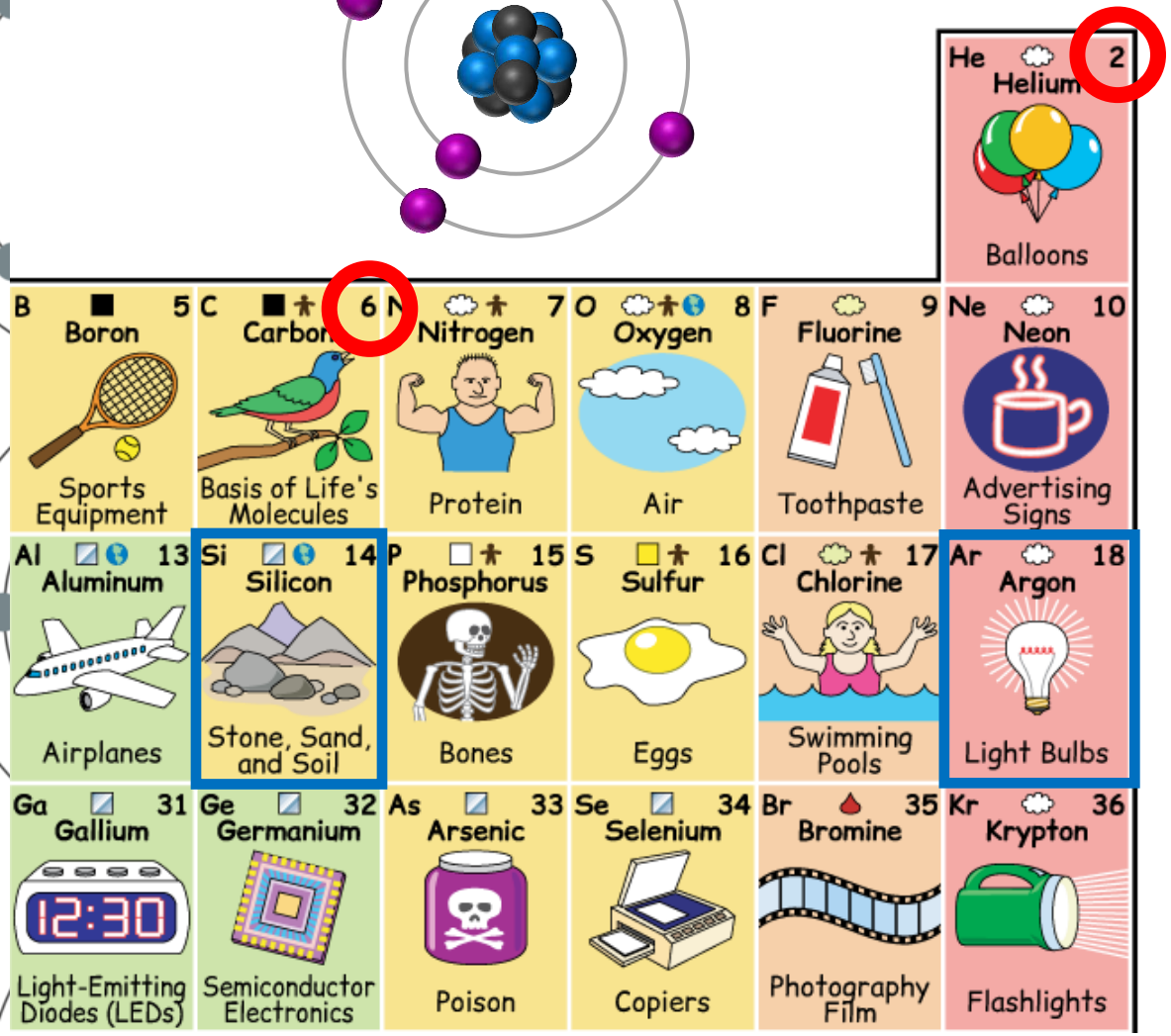


The number shown on each element is the **atomic number**. For example, helium has an atomic number of 2, which means it has two protons and two electrons.



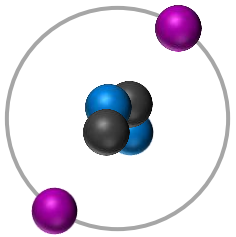
Carbon



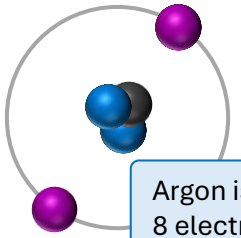


Pure silicon makes itself stable by sharing electrons with four neighbours, causing silicon to form a crystal with the same structure as diamond.

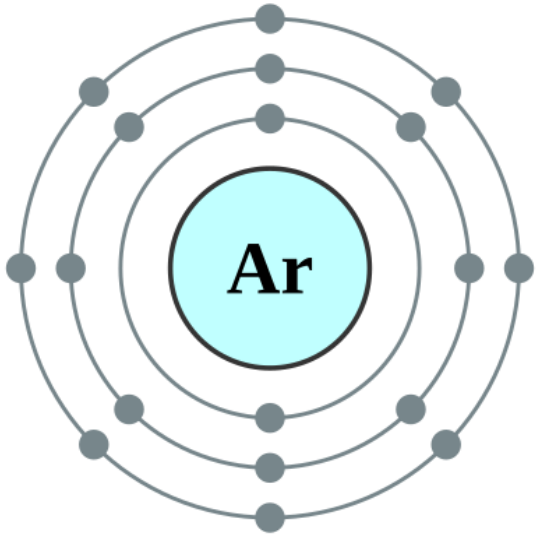
Helium



proton +
electron –
neutron

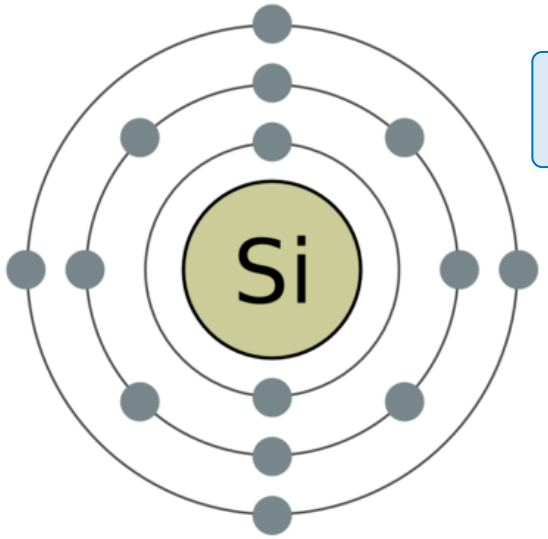


Argon is stable because it has 8 electrons in its outer shell.



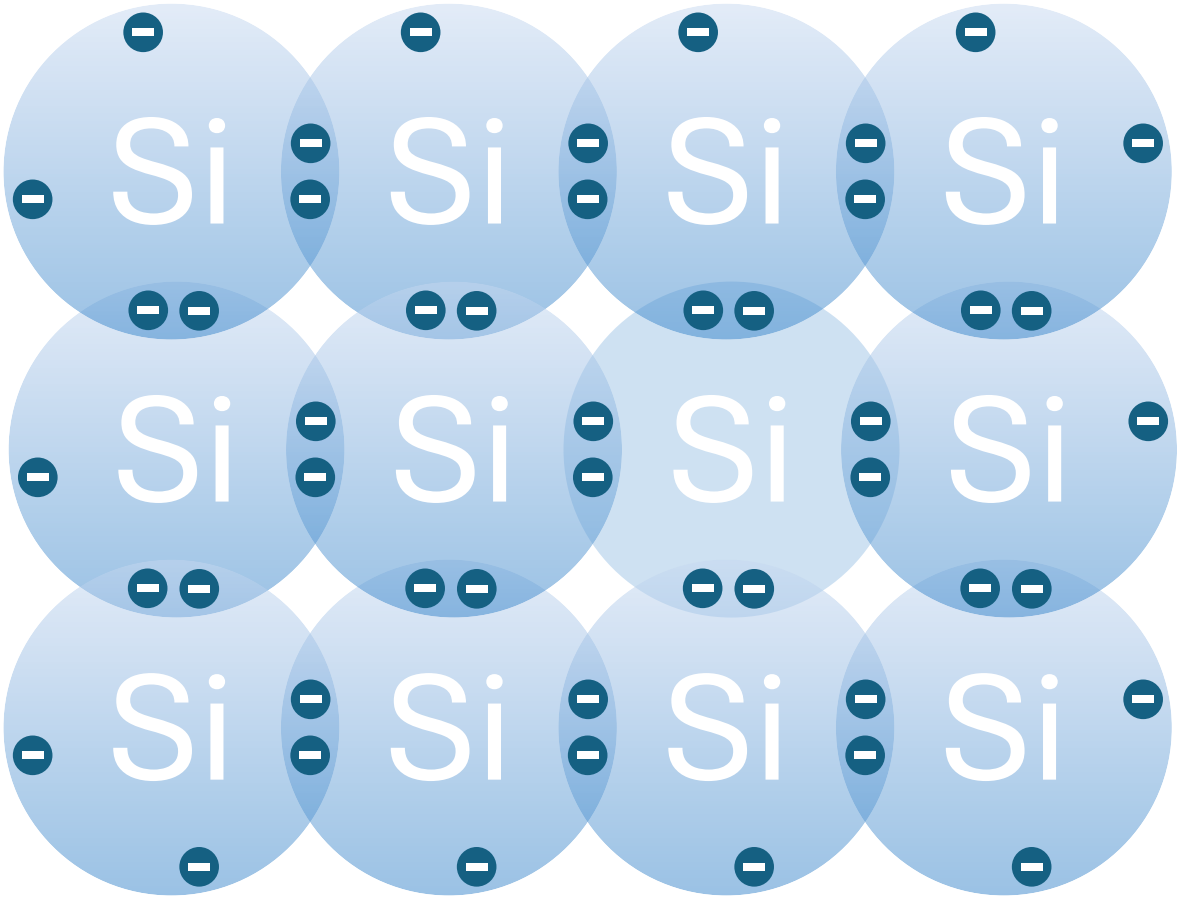
Silicon by Enricoros / ⊘
Silicone by OttawaAC / CC BY-SA 3.0
Silicon by Greg Robson / CC-BY-SA-2.0-UK
Periodic Table by Keith Enevoldsen / CC BY-SA 4.0
Argon by Pumbaa & Greg Robson / CC-BY-SA-2.0-UK
Silicone by Achim Hering / CC BY 3.0
Silicone by OttawaAC / CC BY-SA 3.0

Semiconductors



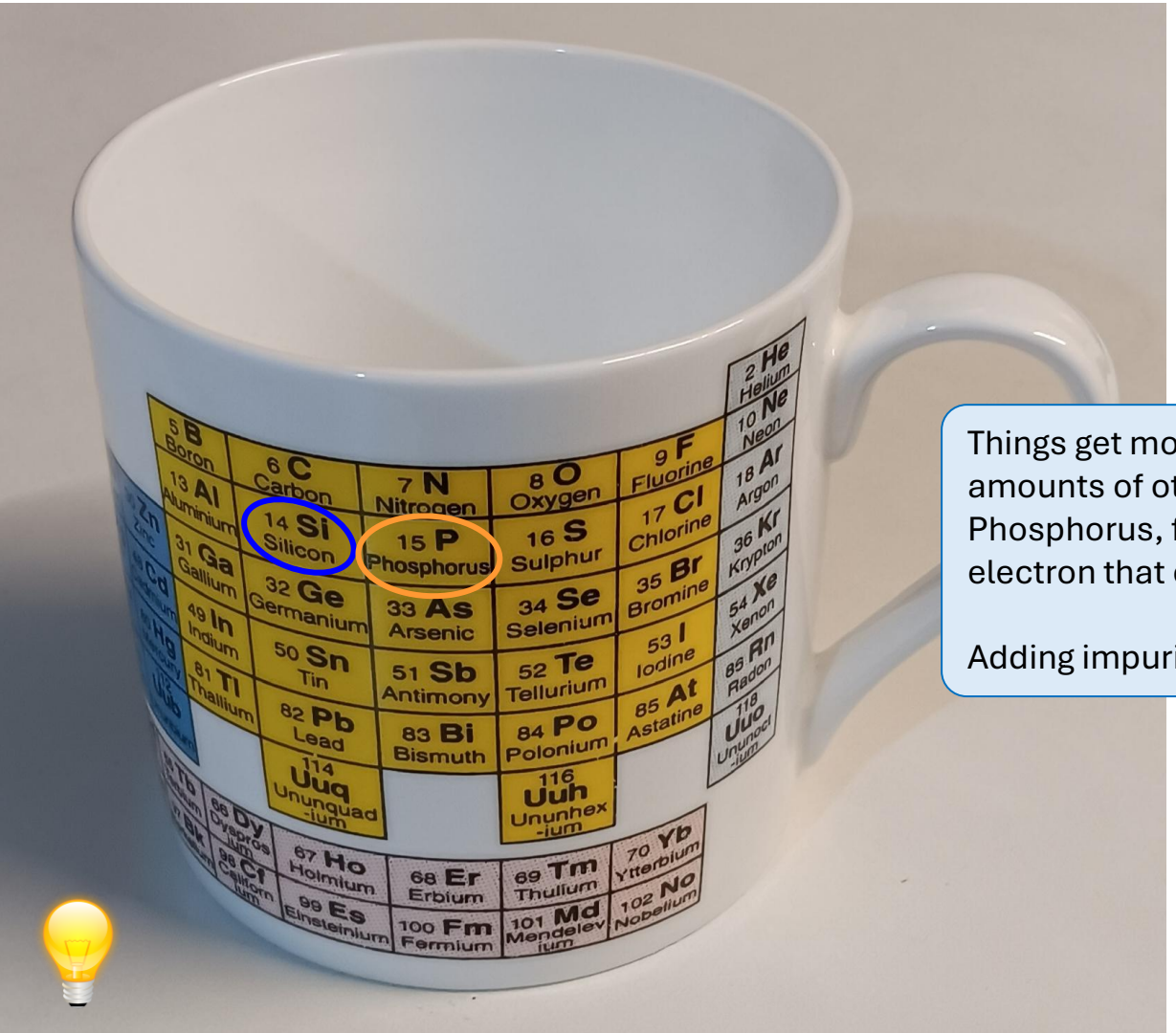
Before the advent of electronics, pure silicon was completely useless.

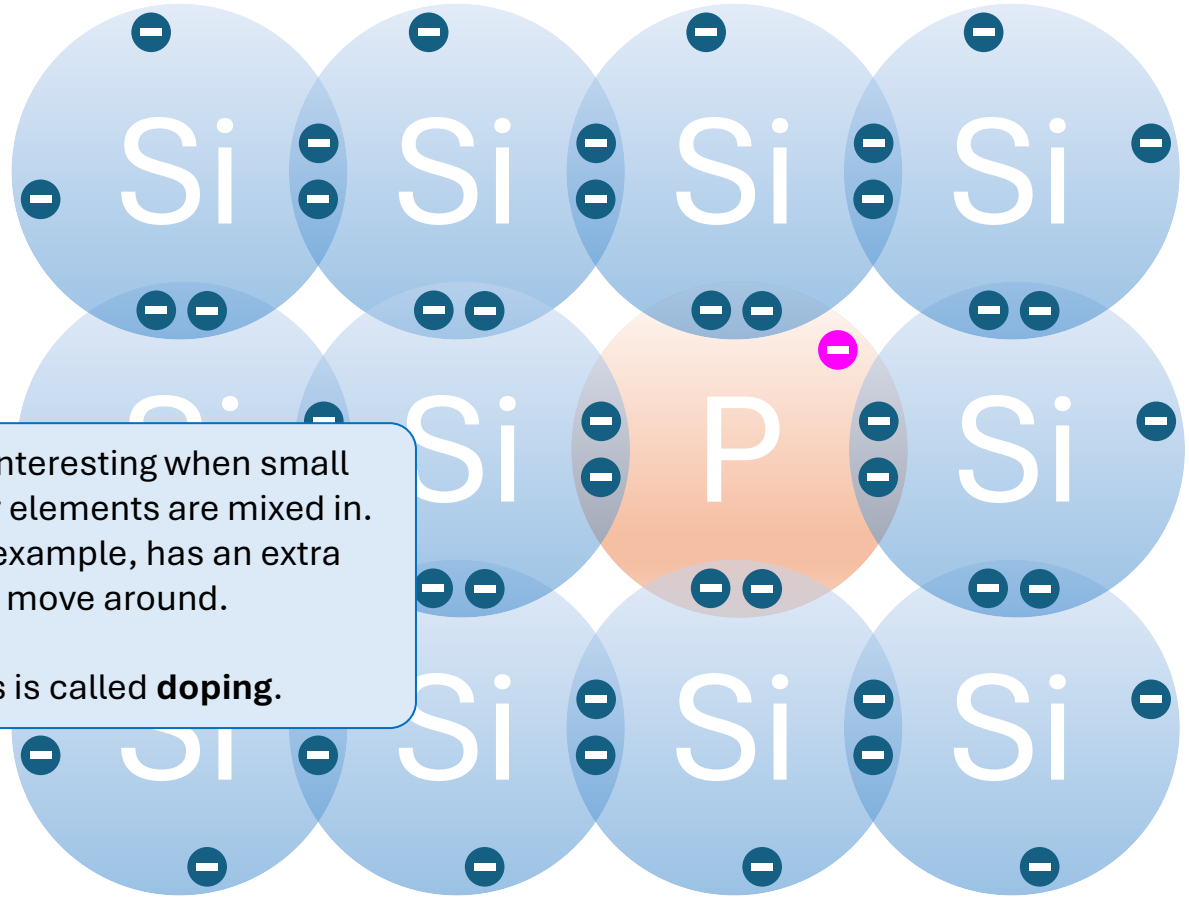
Mundane, stubborn, and profoundly disappointing



Semiconductors

electron

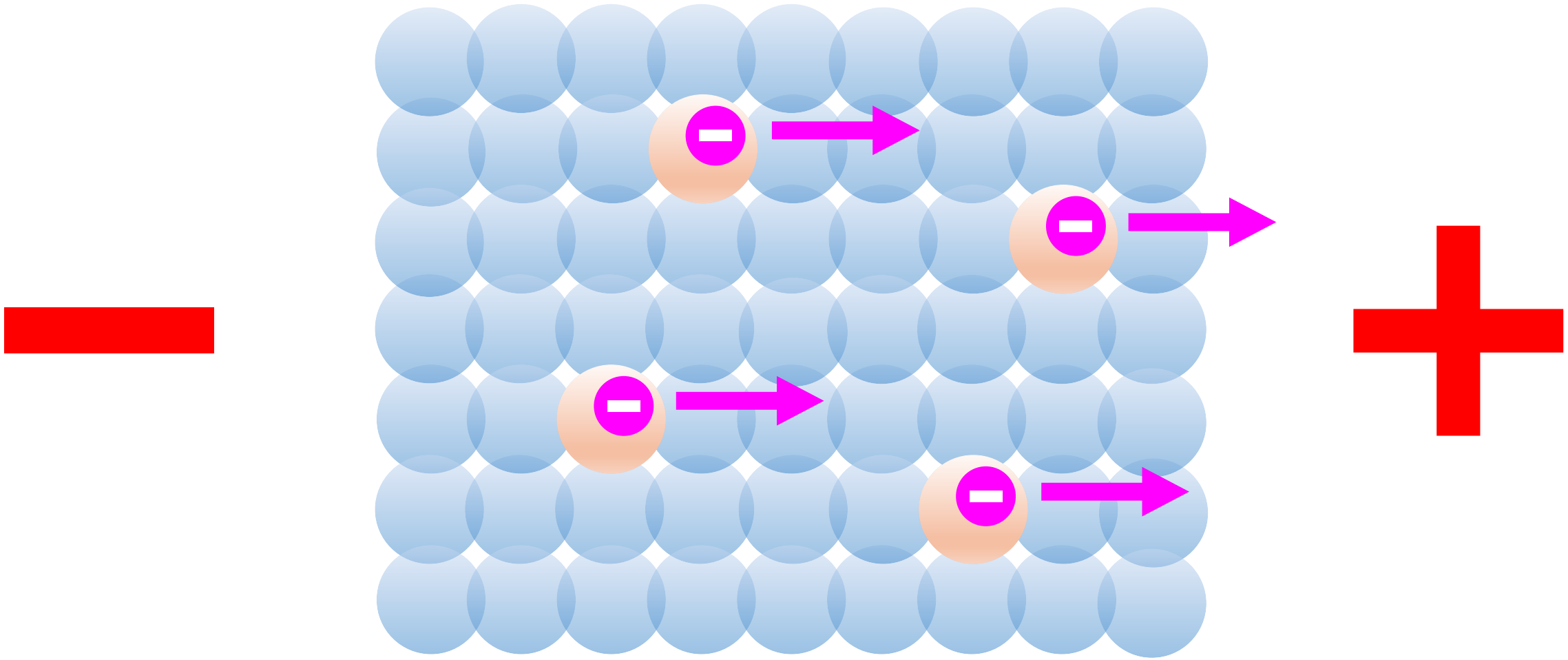




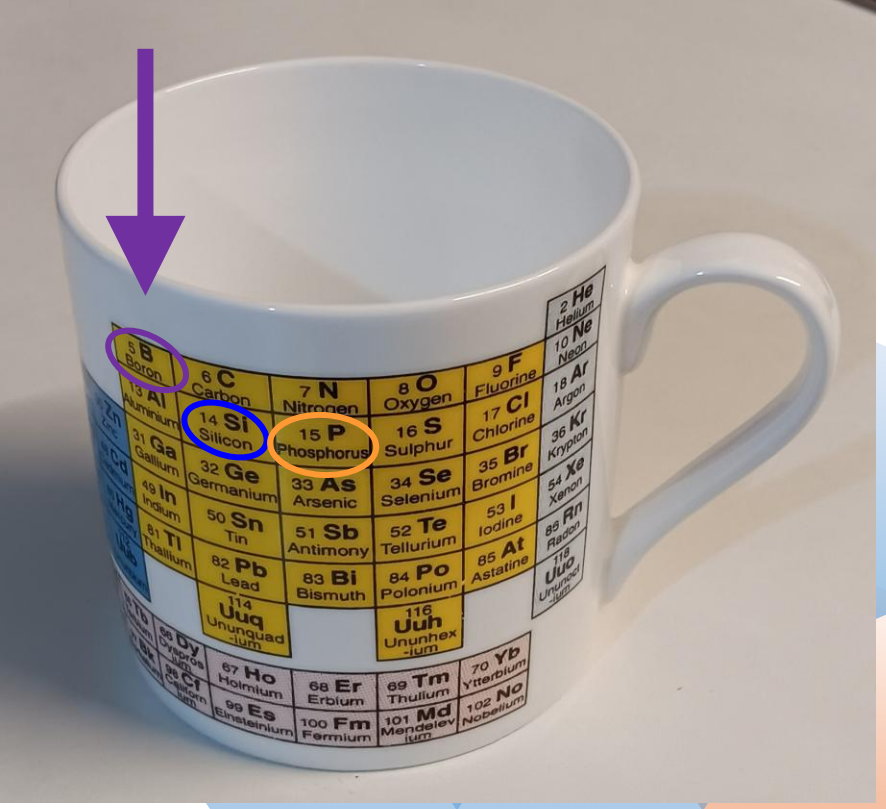
Things get more interesting when small amounts of other elements are mixed in. Phosphorus, for example, has an extra electron that can move around.

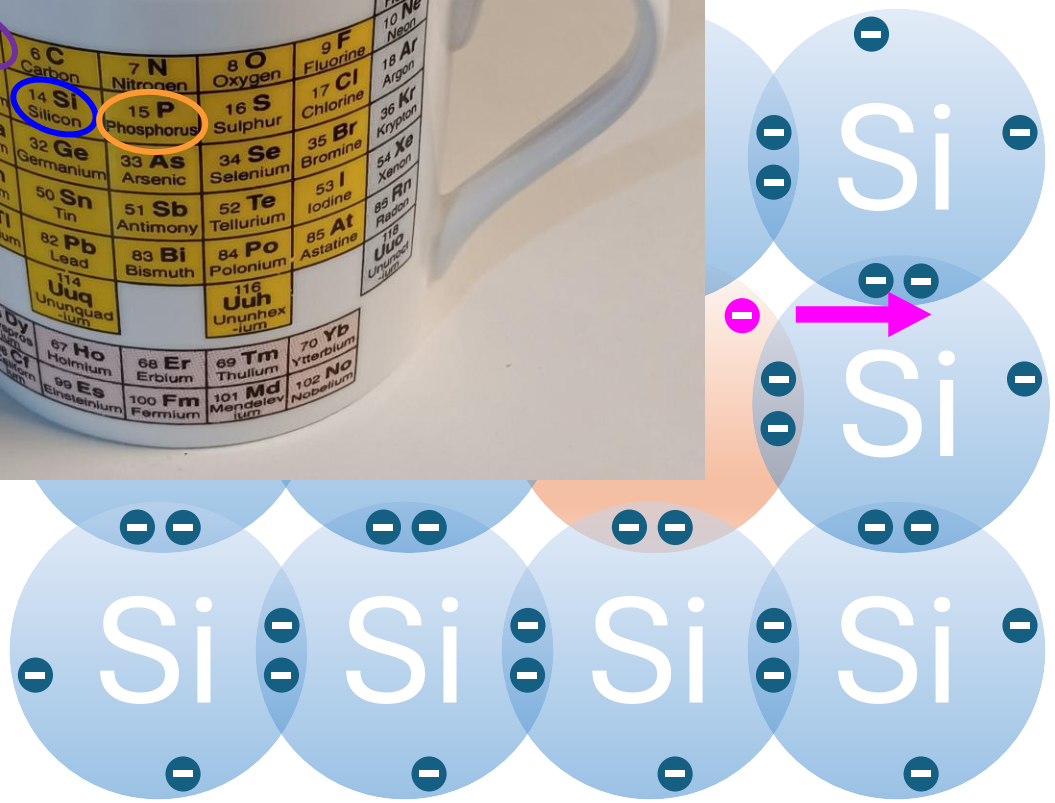
Adding impurities is called **doping**.

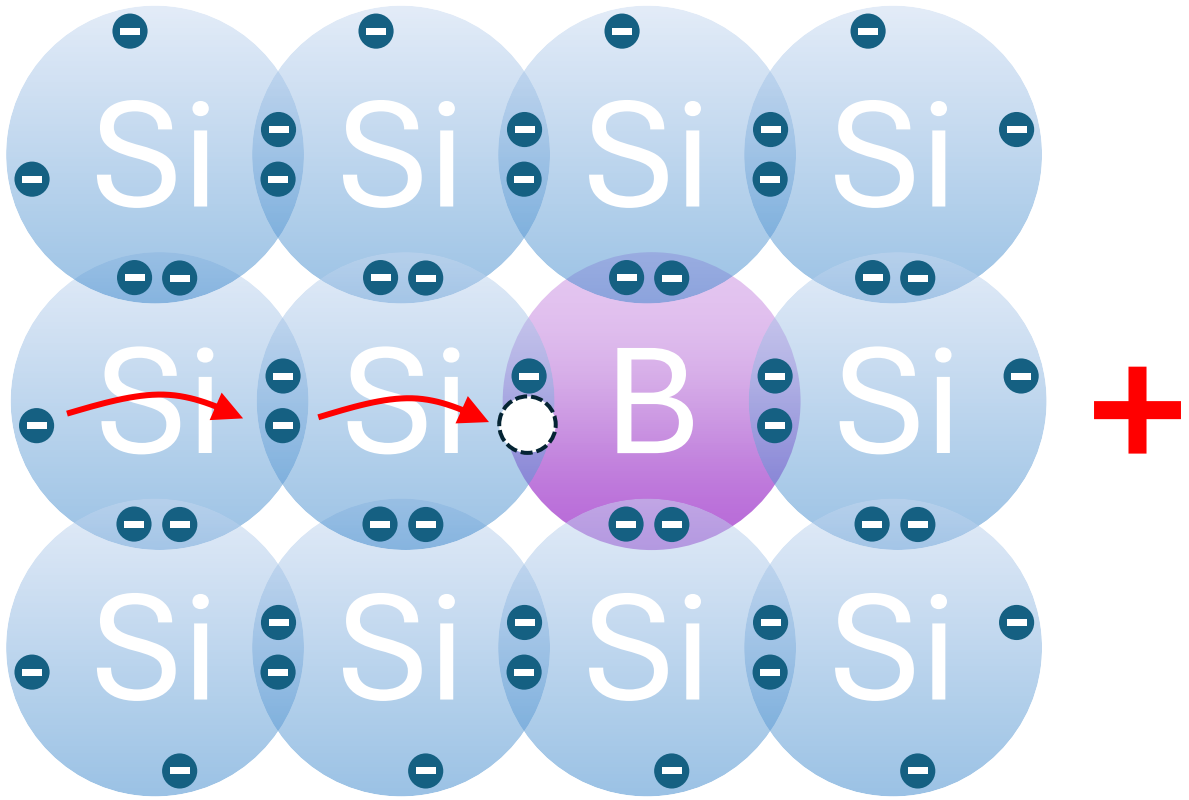
When a voltage is applied, the spare electrons move, allowing the doped silicon to be a conductor.



Doping with boron introduces a hole, due to the missing electron. When a voltage is applied, a neighbouring electron can move into the hole, making the hole move the left.







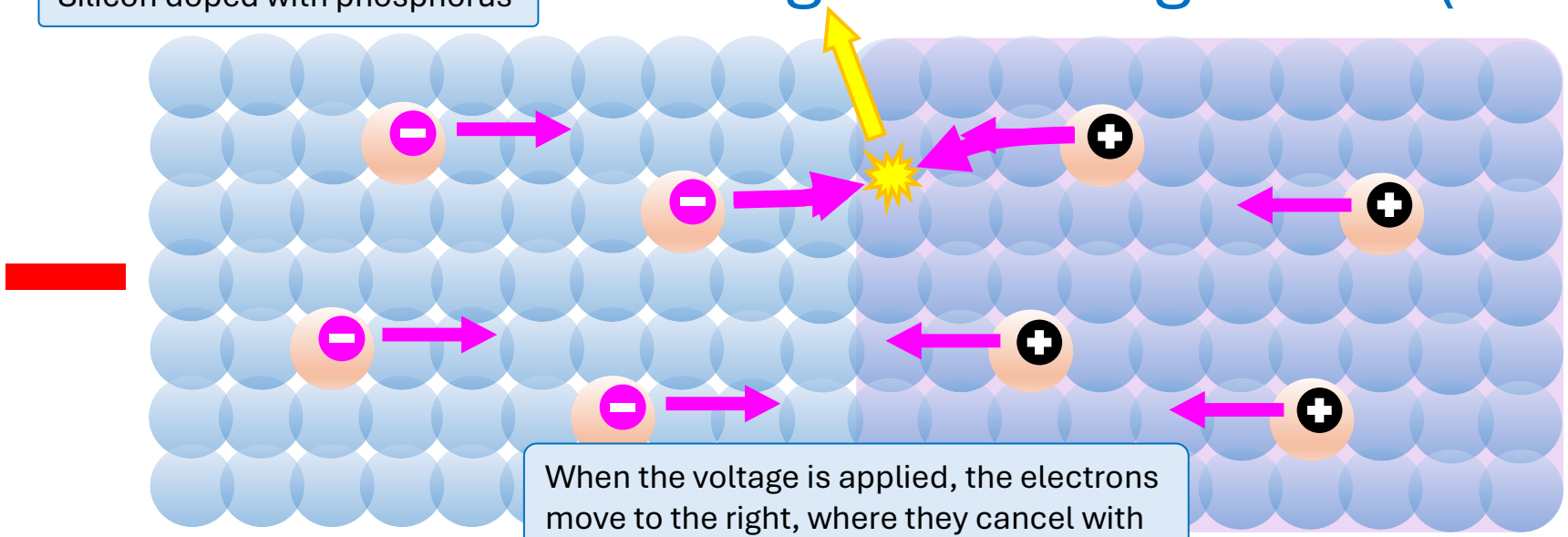
Electron →

← Electron hole

Light emitting diode (LED)

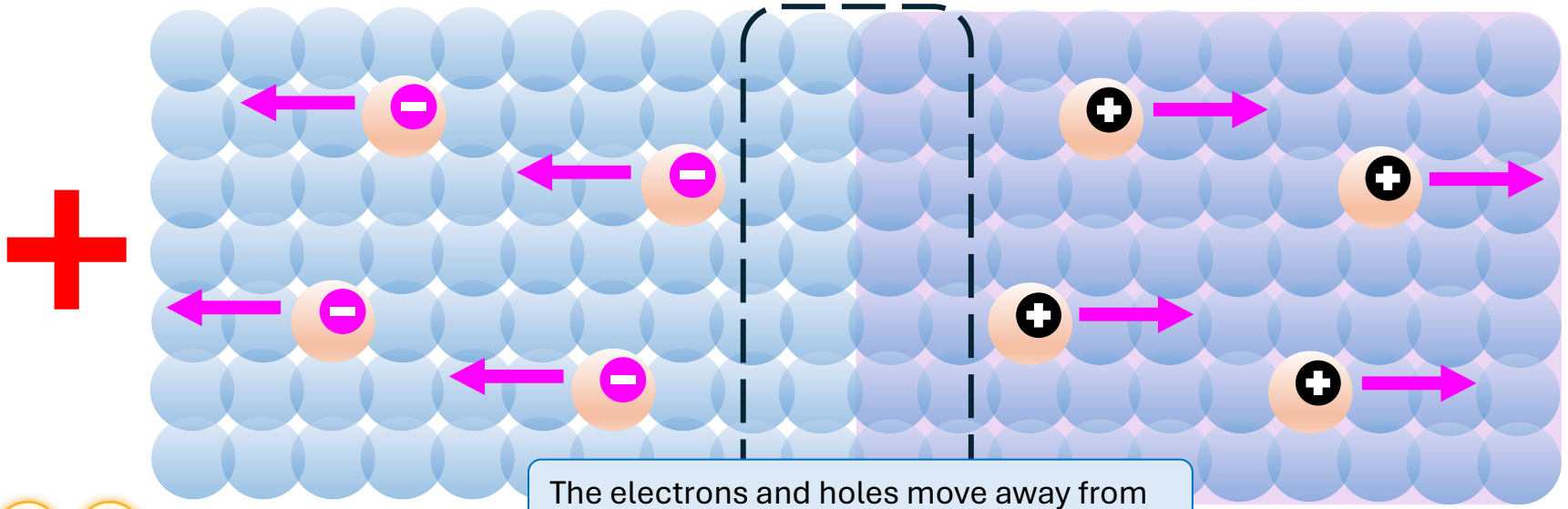
Diode

Silicon doped with phosphorus



Silicon doped with boron

When the voltage is applied, the electrons move to the right, where they cancel with the holes coming the other way.

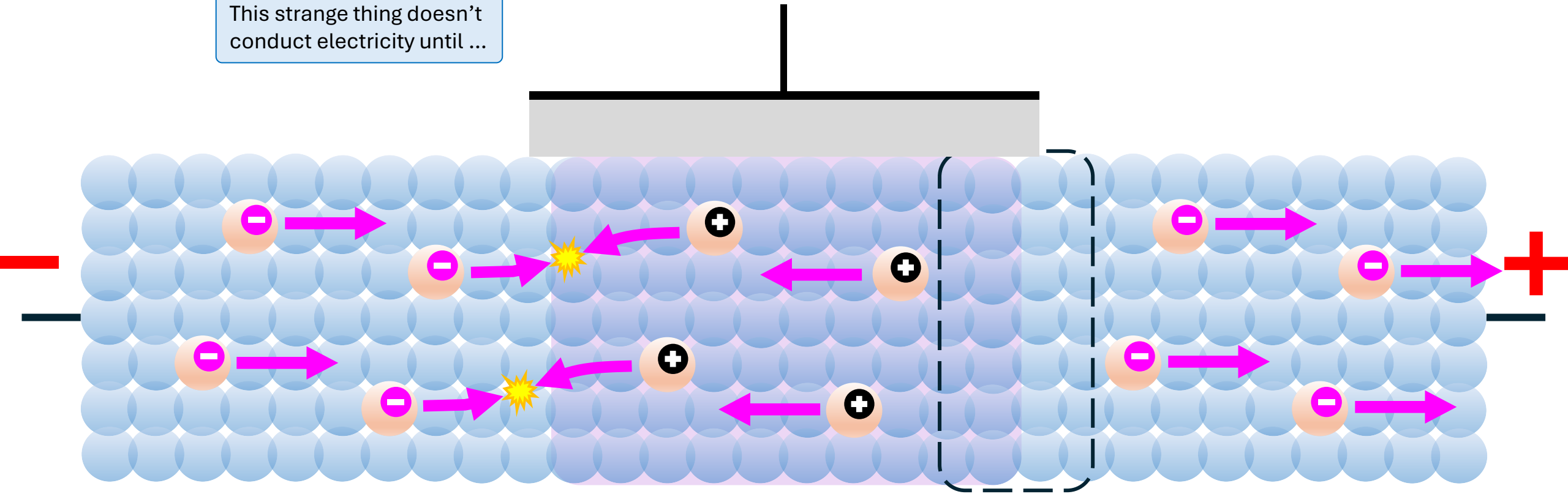


doesn't conduct

one way only!

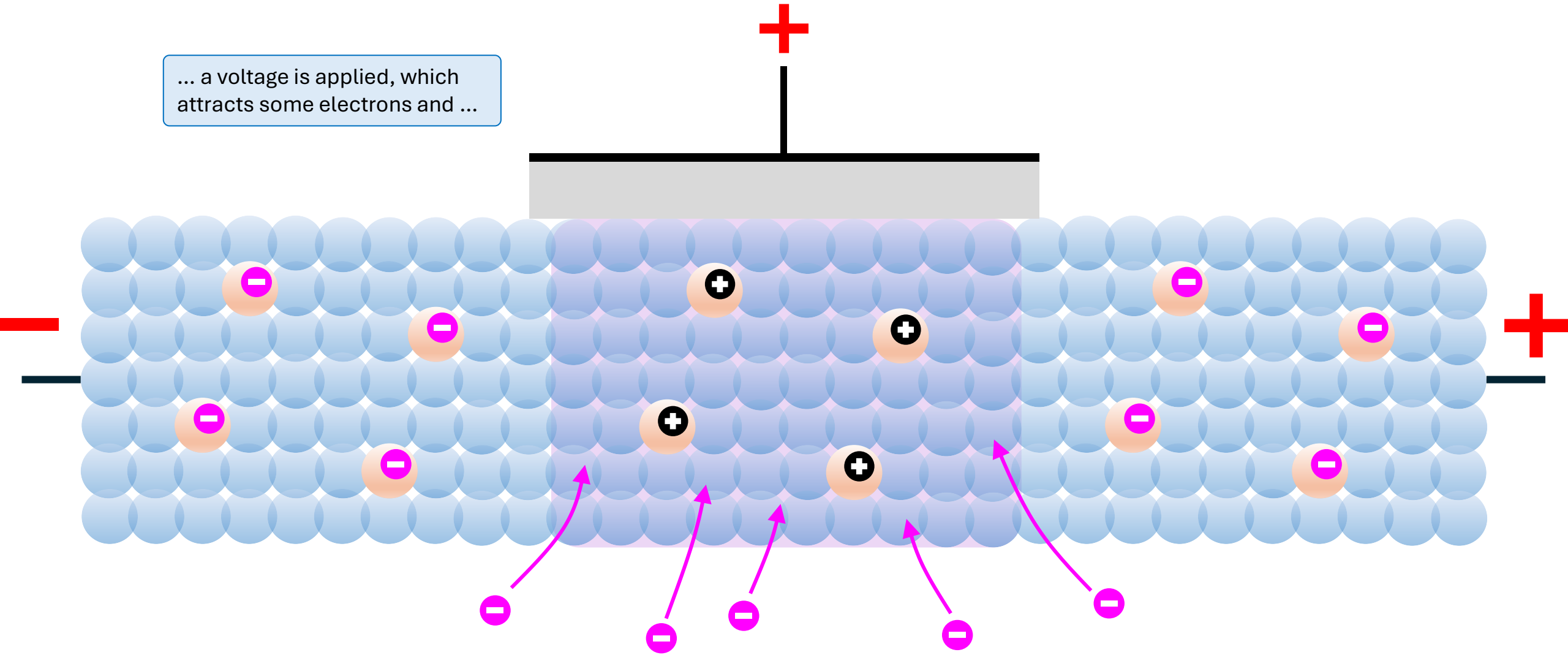
The electrons and holes move away from the boundary, leaving a depletion zone and preventing any conduction.

This strange thing doesn't conduct electricity until ...

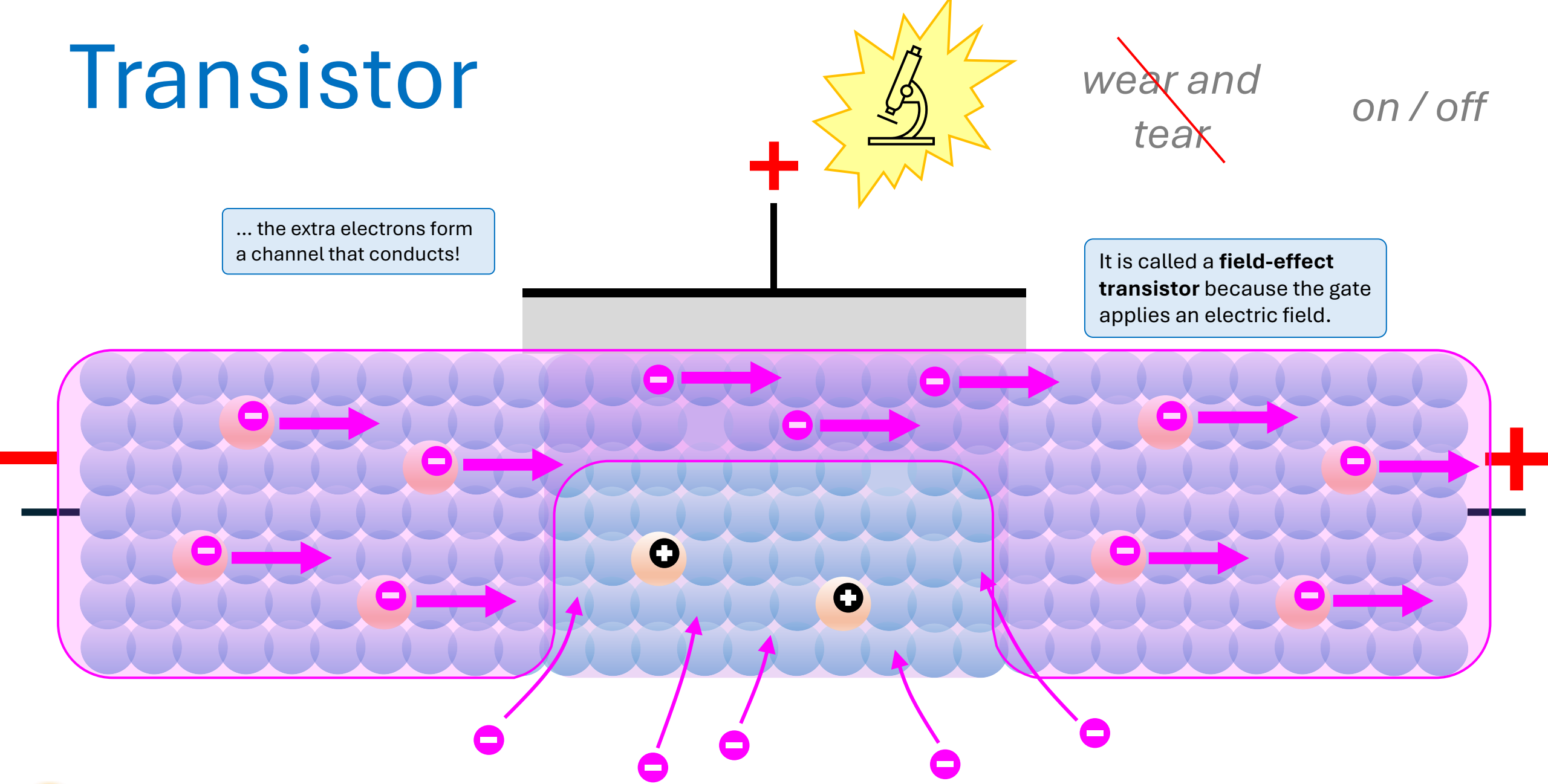


Transistor

... a voltage is applied, which attracts some electrons and ...



Transistor


wear and tear
on / off
... the extra electrons form a channel that conducts!
It is called a **field-effect transistor** because the gate applies an electric field.

10^{160} permutations of two packs of cards

10^{140}

10^{22} transistors in the world

10^{120} ... an astronomical number

10^{100} the observable universe as a computer

10^{80} atoms in the observable universe

10^{60} permutations of a pack of cards

10^{40}

10^{20} stars in the observable universe

transistors

GPT-3 training run

all the computers for a year

10^{22} divided by 8 billion people is over a trillion (which I see now isn't really trillions).

This one is genuinely trillions, because there are only 30 million seconds in a year.

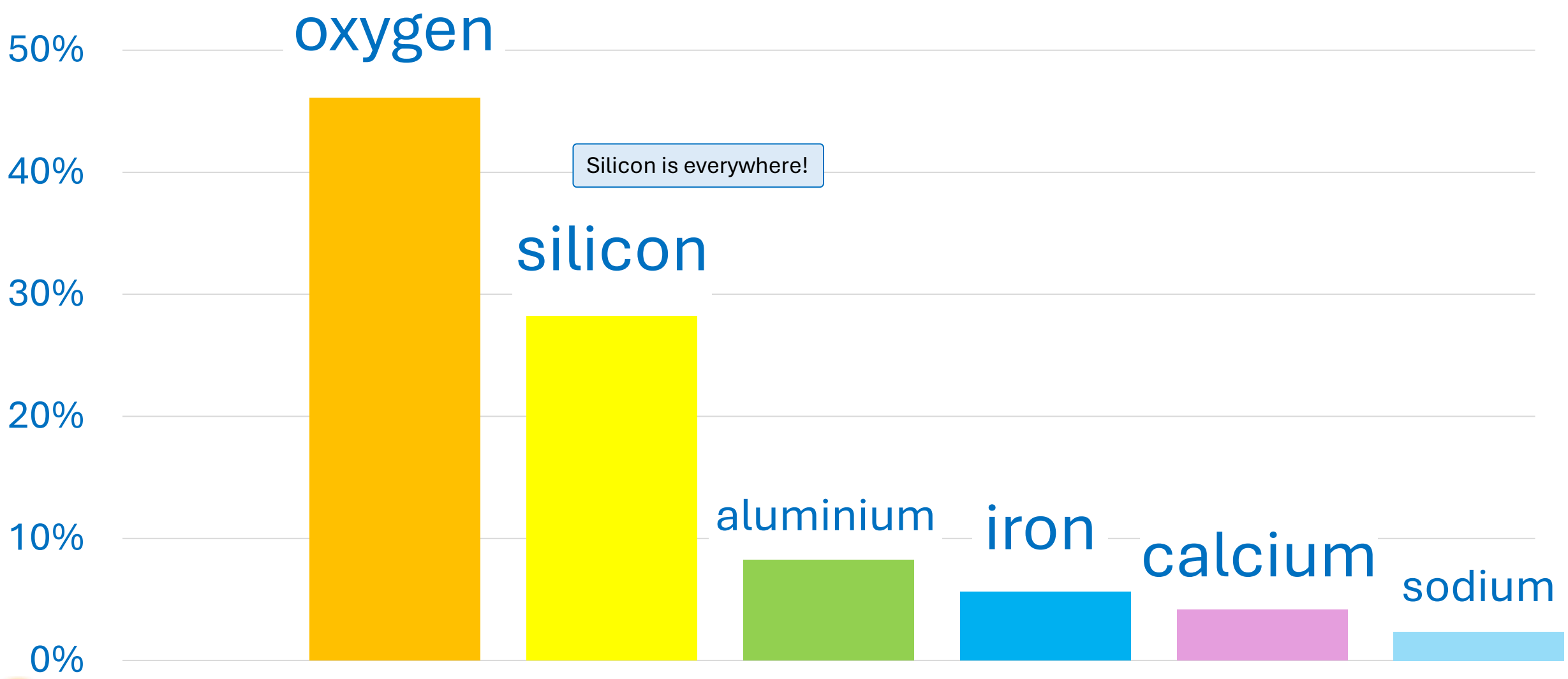
1 trillions per person

trillions per second

(A CPU is a sea of transistors)

silicon

Abundance of chemical elements in Earth's (continental) crust, by mass



https://en.wikipedia.org/wiki/Abundance_of_elements_in_Earth%27s_crust#List_of_abundance_by_element

Jan Czochralski

Czochralski discovered that a single crystal can be pulled out of molten silicon.

He made this discovery by accident: instead of dipping his pen into his inkwell, he dipped it in molten tin, and drew a tin filament, which later proved to be a single crystal.

1915

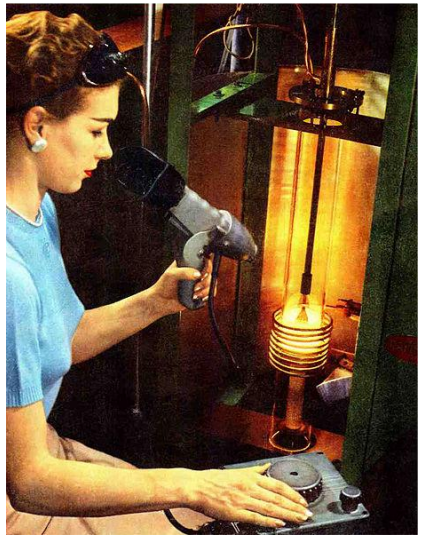
sand

silicon

99.9999999%

quartz

The Czochralski process is still used today.



1956

Czochralski process

crystal

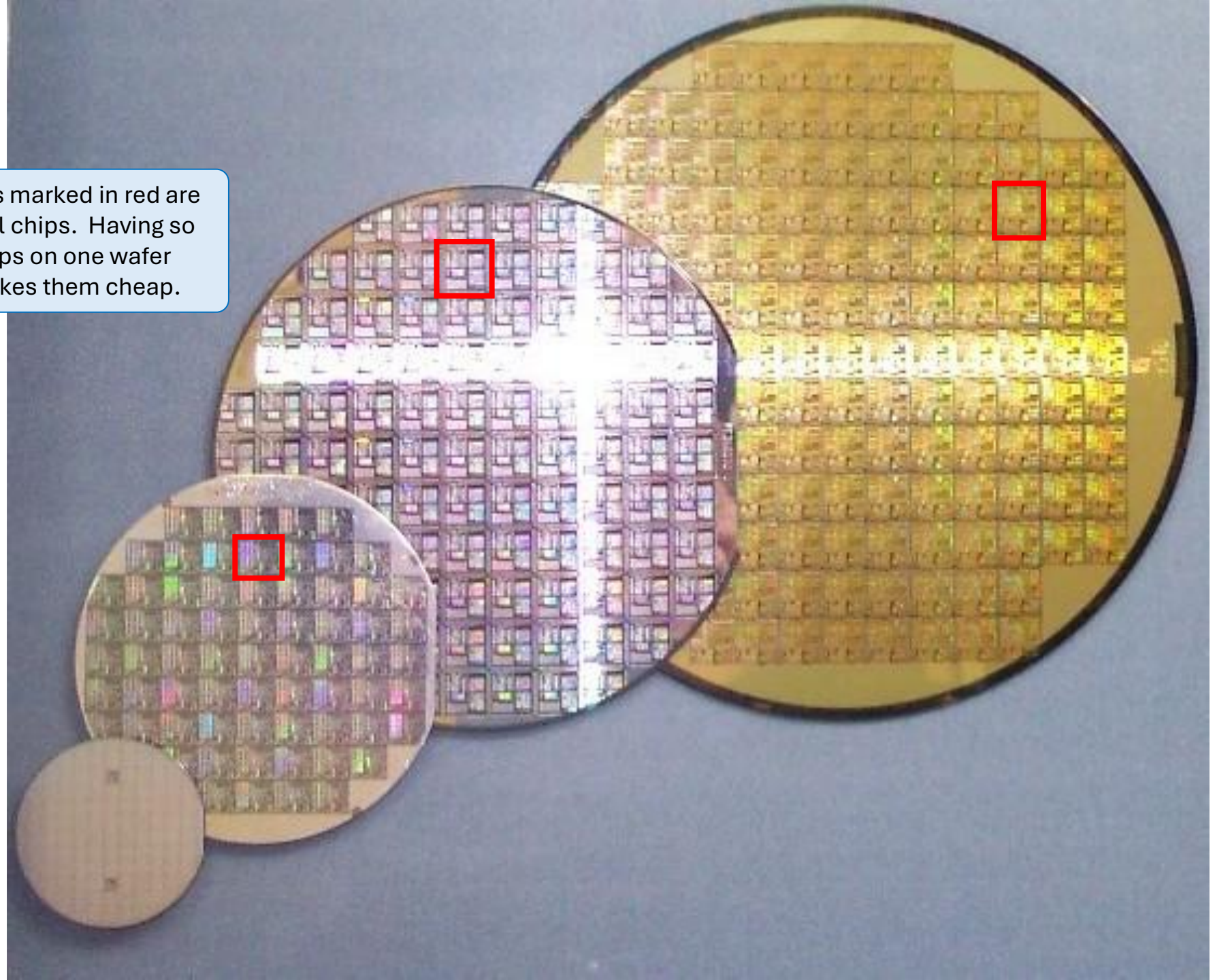
The ingot of pure silicon is divided into very thin slices and then etched with the intricate patterns that makes the transistors etc.

Wafer by Stahlkocher / CC BY-SA
Crystal by Intel Free Press / CC BY-SA 2.0
Silicon by Enricoros /
Sand by Falkenpost / Pixabay
Quartz by alusruvi / CC0
Czochralski by Unknown Author / CC BY-SA
Growing a crystal by George E. Meyers /

https://www.google.com/search?udm=2&q=wafer

(image search)

The areas marked in red are individual chips. Having so many chips on one wafer helps makes them cheap.



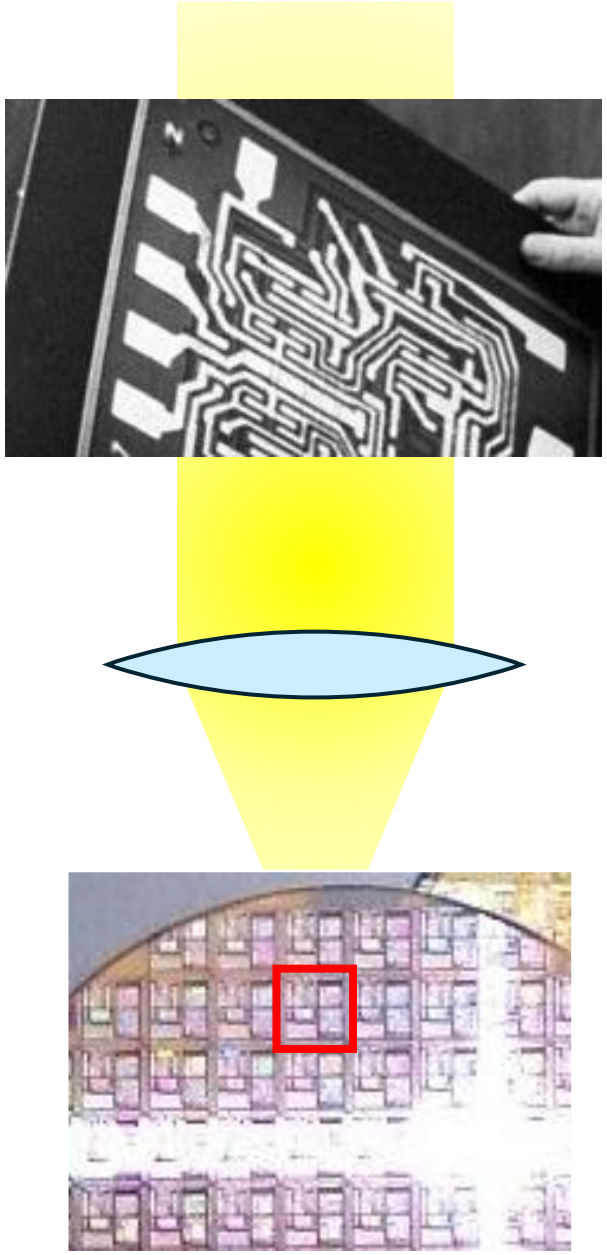
1959

Robert Noyce

Fairchild

Intel

Robert Noyce, cofounder of Fairchild and then Intel, invented the first **integrated circuit**, a collection of transistors (and wires and so on) etched onto a single piece of silicon.



Photolithography

Etching

Chemical vapour deposition

Chips are made by a long sequence of operations, including shining light patterns onto photosensitive materials.

In modern fabs, like the ones at TSMC, a wafer is carried on tracks from one chamber to another for a period of three months!

Robert Noyce by Intel Free Press / CC BY-SA 2.0

https://en.wikipedia.org/wiki/Semiconductor_fabrication_plant

Apple, Nvidia, ARM, ... *fabless*

TSMC – Taiwan *makes the chips*

semiconductor

ASML – Netherlands *makes the machines that make the chips*

https://www.google.com/search?udm=2&q=chip+fab

https://www.google.com/search?udm=2&q=ASML

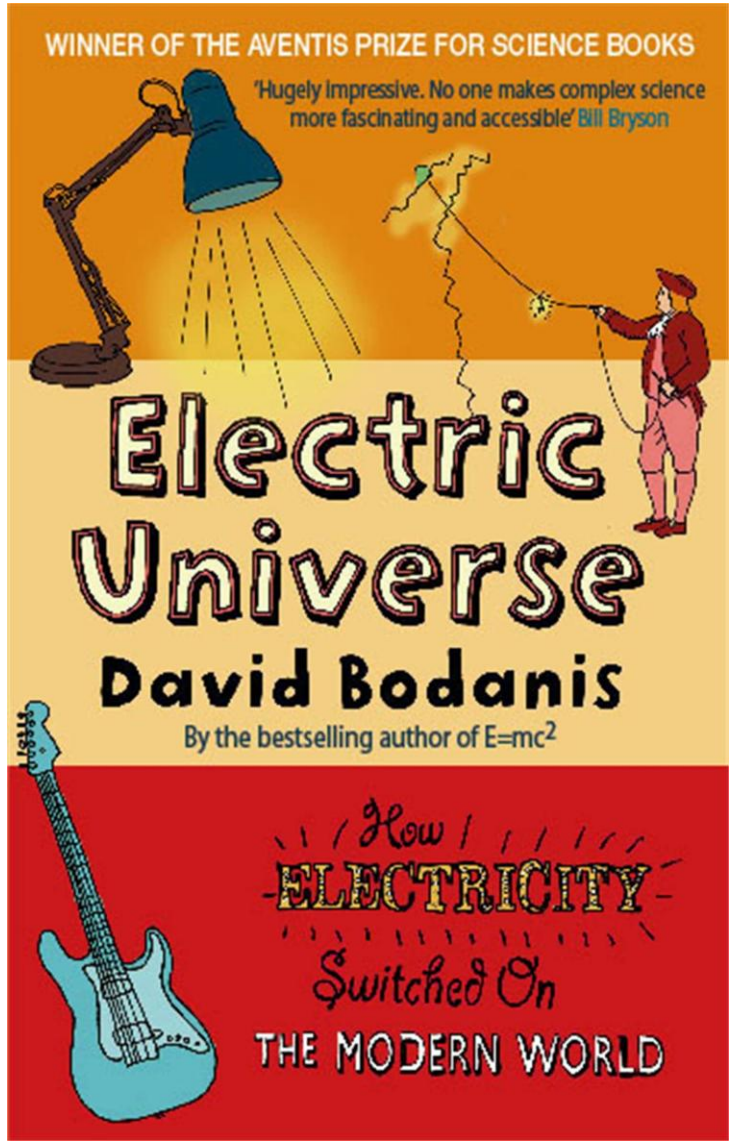
Lilienfeld
1926

The first patent for a field-effect transistor

Bardeen Shockley Brattain

The first working transistor

1947



Lilienfeld / CC0
Bipolar Junction Transistor / CC0

Long-term memory

Magnetic tape

Hard disk drive

Short-term memory

RAM

Random-access memory

Memory

Short-term memory

Central-processing unit
CPU

+ − × ÷

RAM
Random-access memory
Memory

Memory

addresses

bits

bytes

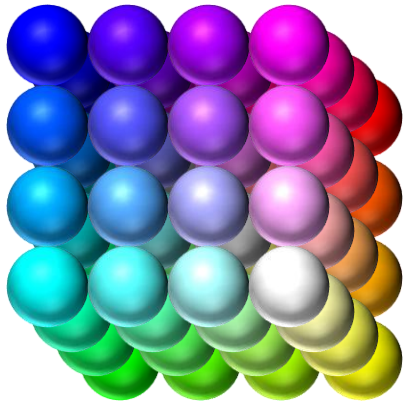
Computers like to count from zero.

0
1
2
...

big

0
1
2
...

flat



森 β ê
ﻫ ぶ

The memory is an open space where colours and writing and so on can be stored anywhere. The lack of boundaries gives great flexibility but can be a source of bugs.

Short-term memory

Central-processing unit
CPU

+ − × ÷

RAM
Random-access memory
Memory

simple

CPU

+ − × ÷

writing

- arbitrary
- complex

Simple computer instructions can be combined into arbitrarily complex sequences, which is what makes the programming possibilities seem so infinite.

A typical computer instruction.

Memory

simple

CPU

+ − × ÷

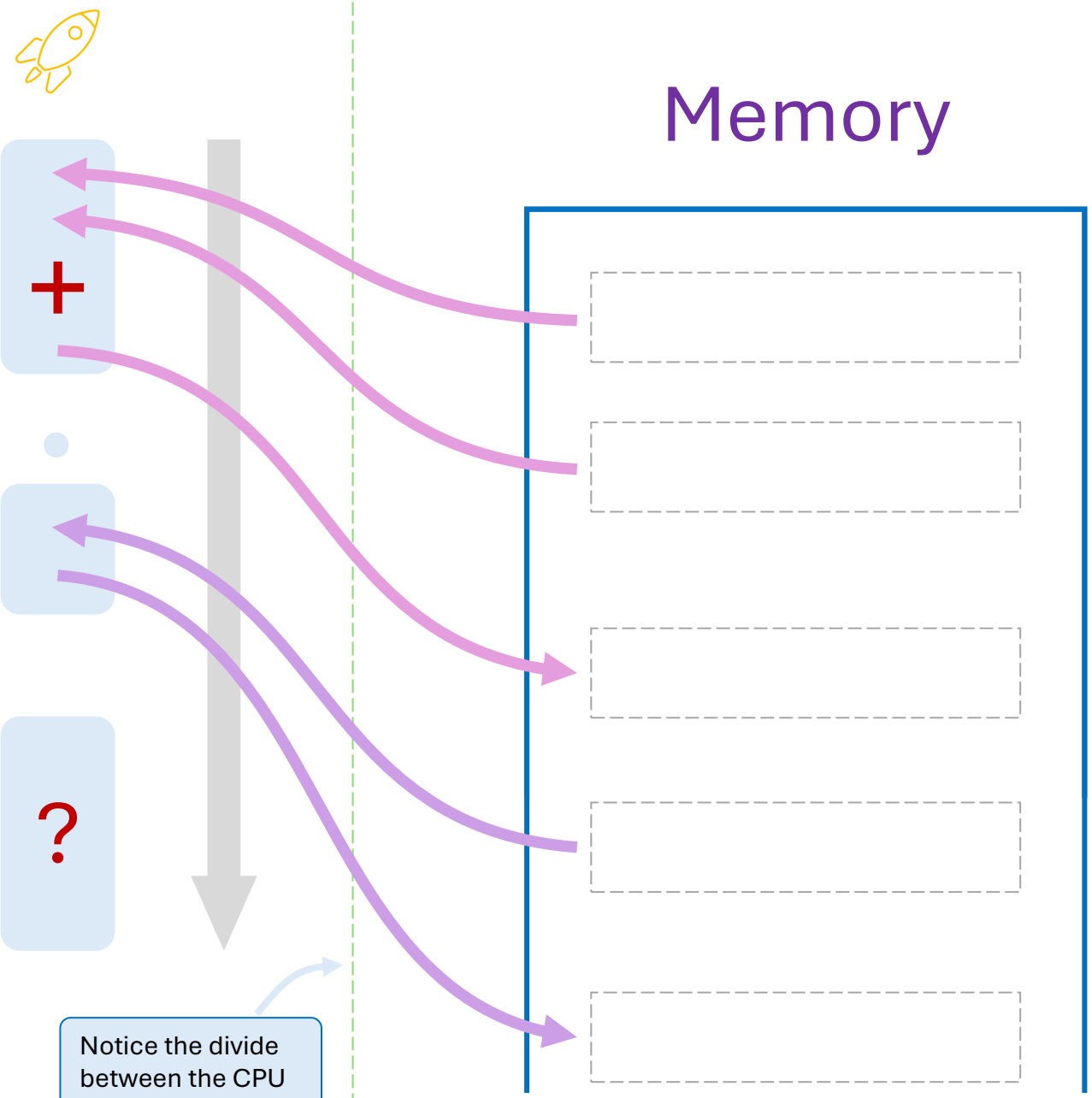
writing

- arbitrary
- complex

decide

Normally a computer obeys the instructions in sequence.

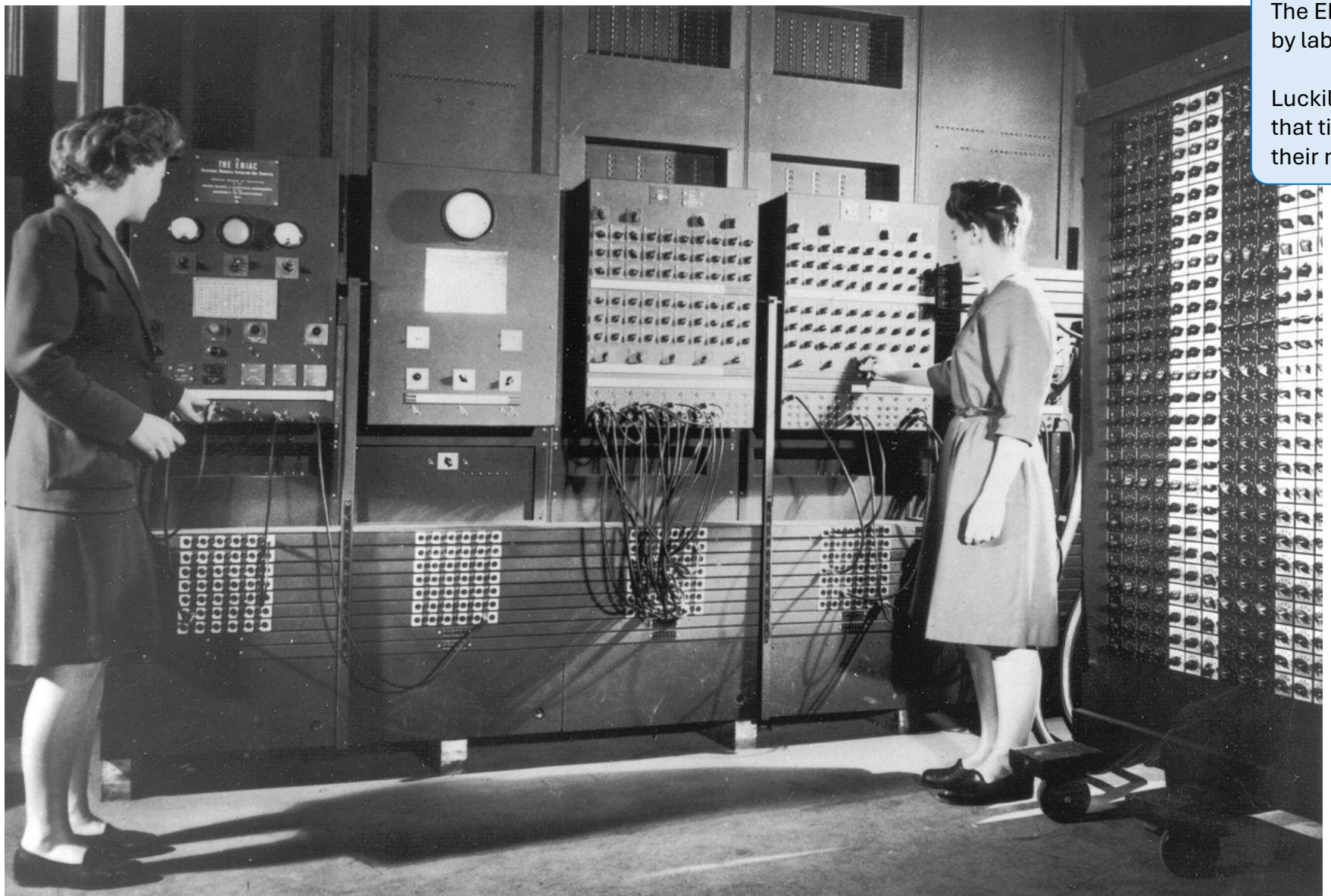
Therefore, a crucial extra ingredient is making simple decisions, that allow the computer to jump around and obey other instructions.



Notice the divide between the CPU and the memory.

ENIAC

Programming the ENIAC



The ENIAC was programmed by laboriously rewiring it.

Luckily, all computers since that time store the program in their memory.

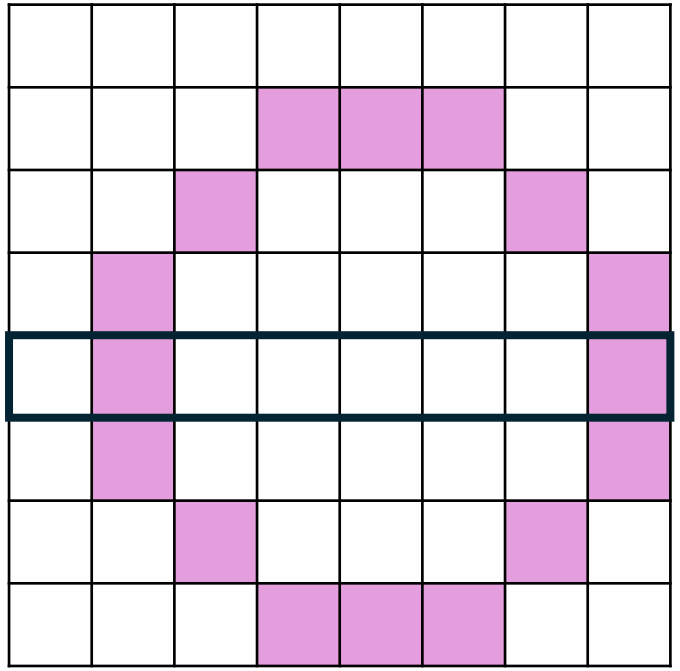
1945

01000001 ‘A’

01000001 65

64 32 16 8 4 2 1

01000001

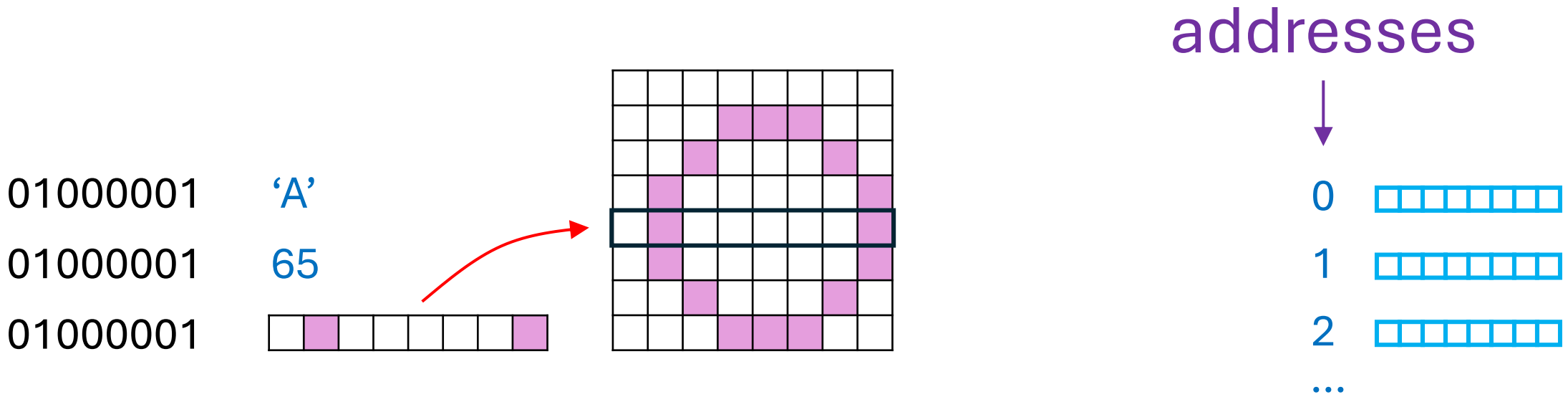


01000001 *a computer instruction*

or part of one

A byte can store a computer instruction in amongst its other data, a major source of opportunities for hackers to confuse the computer.

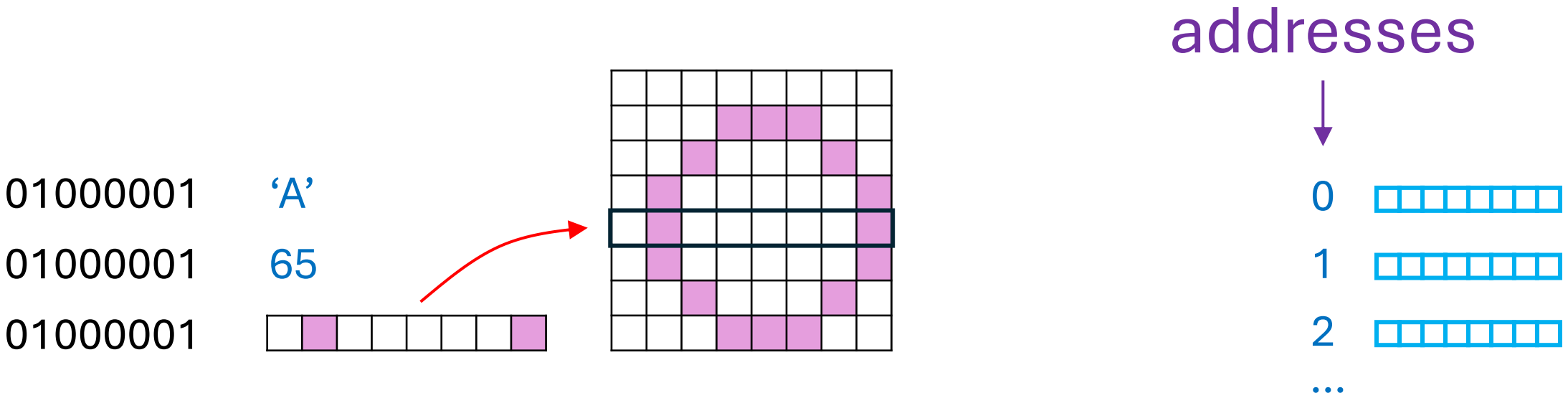
Computer	Brain
Fast	Parallel
Deterministic	Low energy
Understandable	Local memory
Unbelievably good at following instructions	



L	o	n	d	o	n			8,866,180

Y	o	r	k					141,685

?



L	o	n	d	o	n			8,866,180
Y	o	r	k					141,685
C	a	m	b	r	i	d	g	1,694,645,811

big enough?

The 'e' from 'Cambridge' overflowed into the neighbouring memory, causing the number to change dramatically. It is notoriously hard to prevent these kinds of bugs…

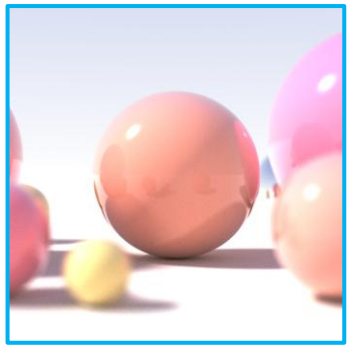
...especially if the names are outlandishly long!

Name by Rob Koster / CC BY-SA 3.0

Parallel computers

Parallel programming is hard!

Ray tracing



Some things like ray tracing are naturally parallel because each pixel's colour is calculated independently...

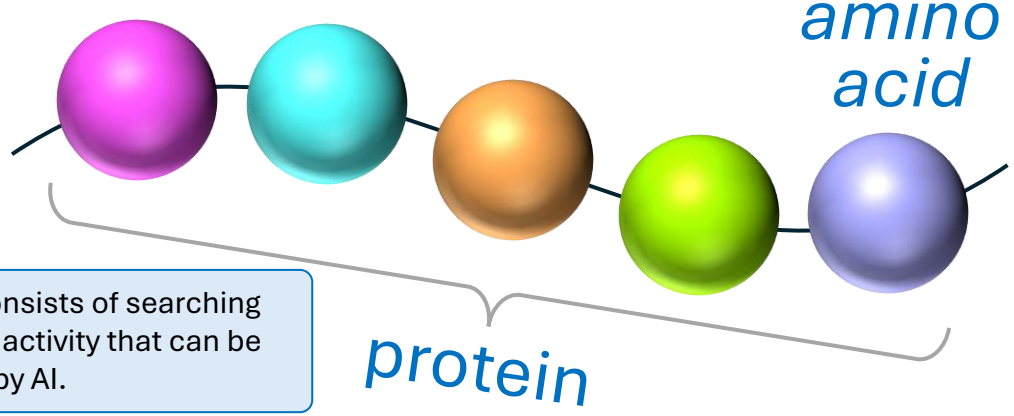
a + b

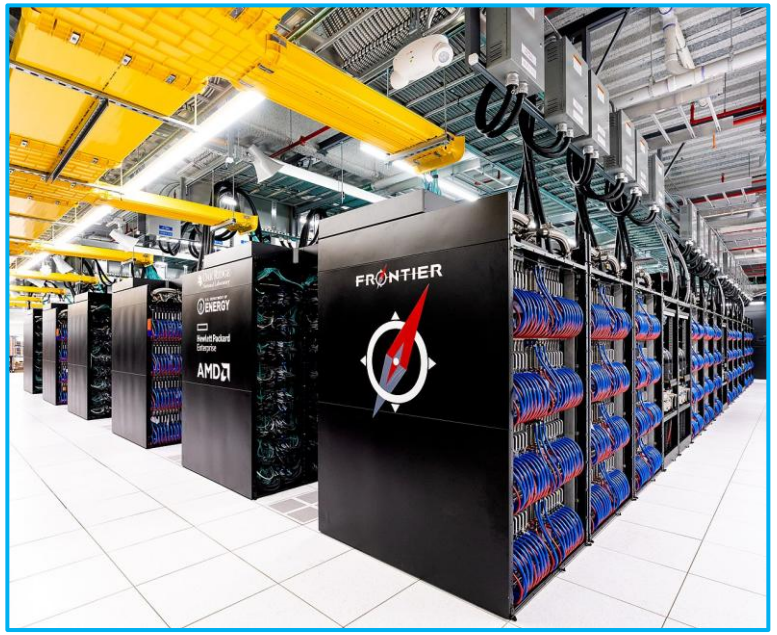
c + d

parallel ☺

Searching

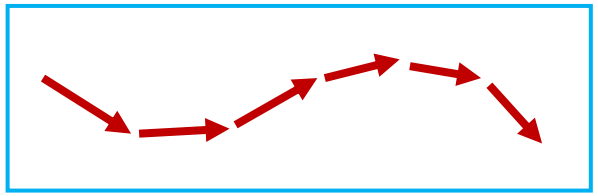
Science often consists of searching for solutions, an activity that can be done in parallel by AI.





This beast has millions of independent processors that must somehow cooperate.

x + y + z ✗



...other things like calculating a trajectory are more sequential.

Frontier by OLCF / CC BY 2.0
Ray tracing by Tim Babb / CC BY-SA 4.0

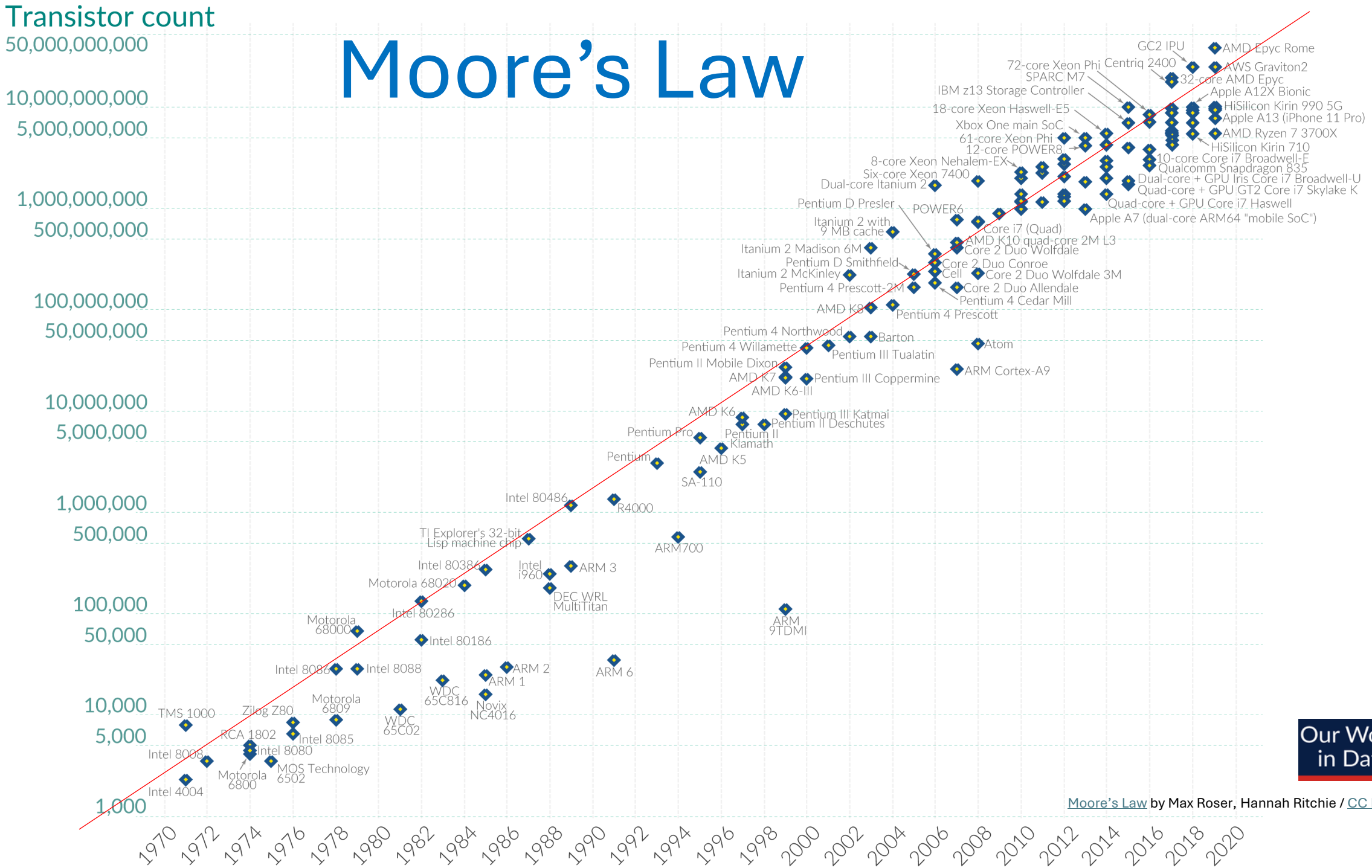
Sequential

- Our conscious thoughts
- 20th century computers

Parallel

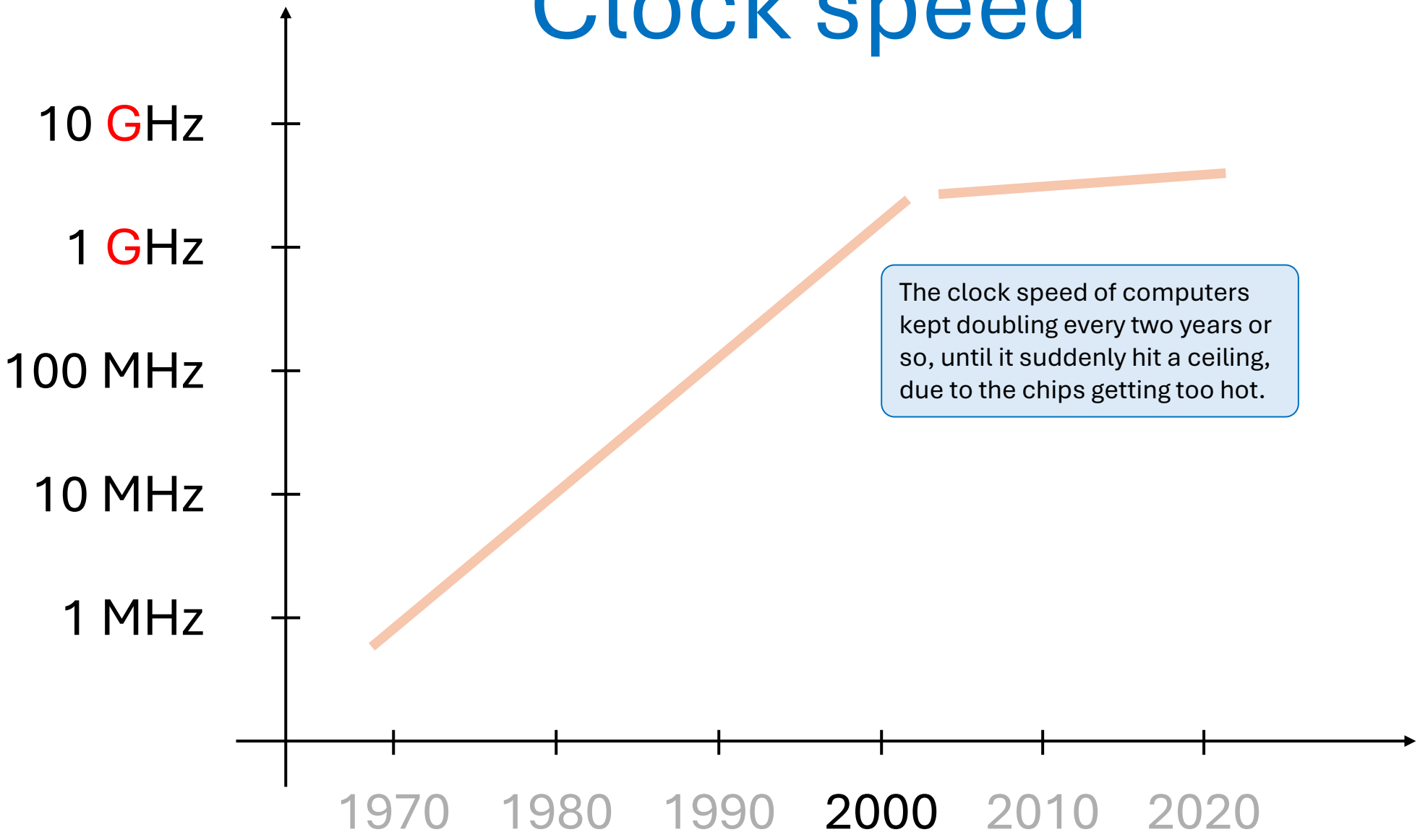
- Our subconscious
- The world

Moore's Law



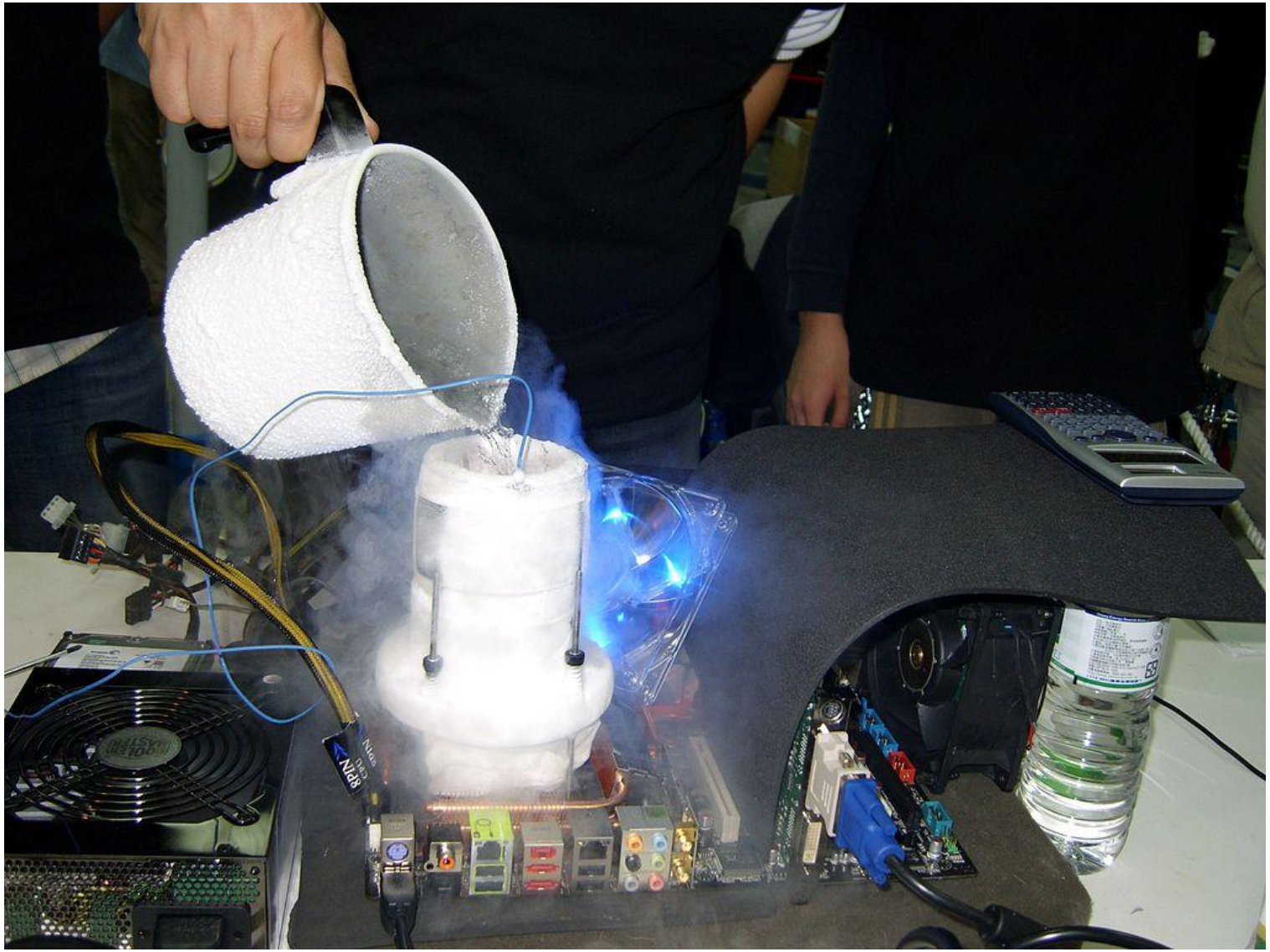
Moore's Law by Max Roser, Hannah Ritchie / CC BY 4.0

Clock speed



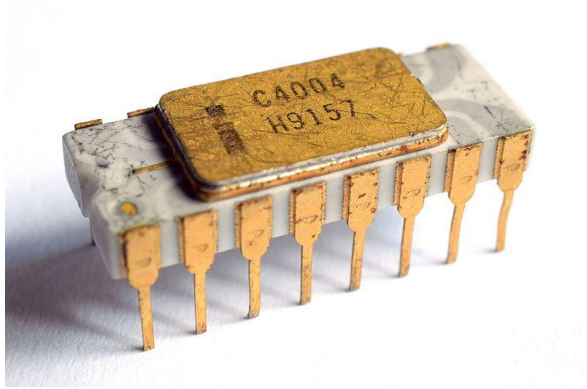
The clock speed of computers kept doubling every two years or so, until it suddenly hit a ceiling, due to the chips getting too hot.

One solution is to bathe the chip in liquid nitrogen.

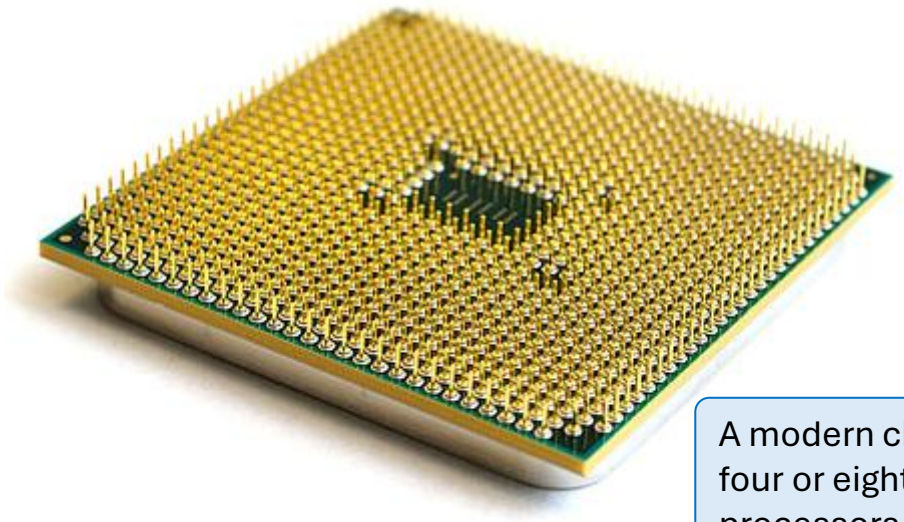


−196 °C

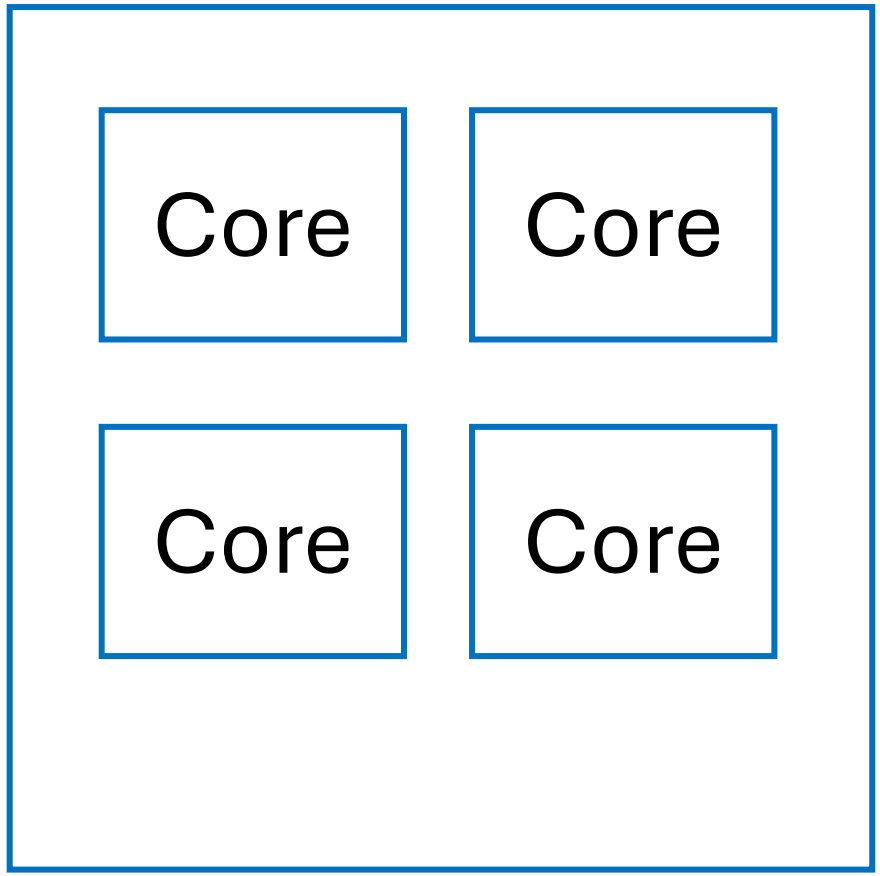
Overclocking by Rico Shen / CC BY-SA 3.0



Quad-core Chip

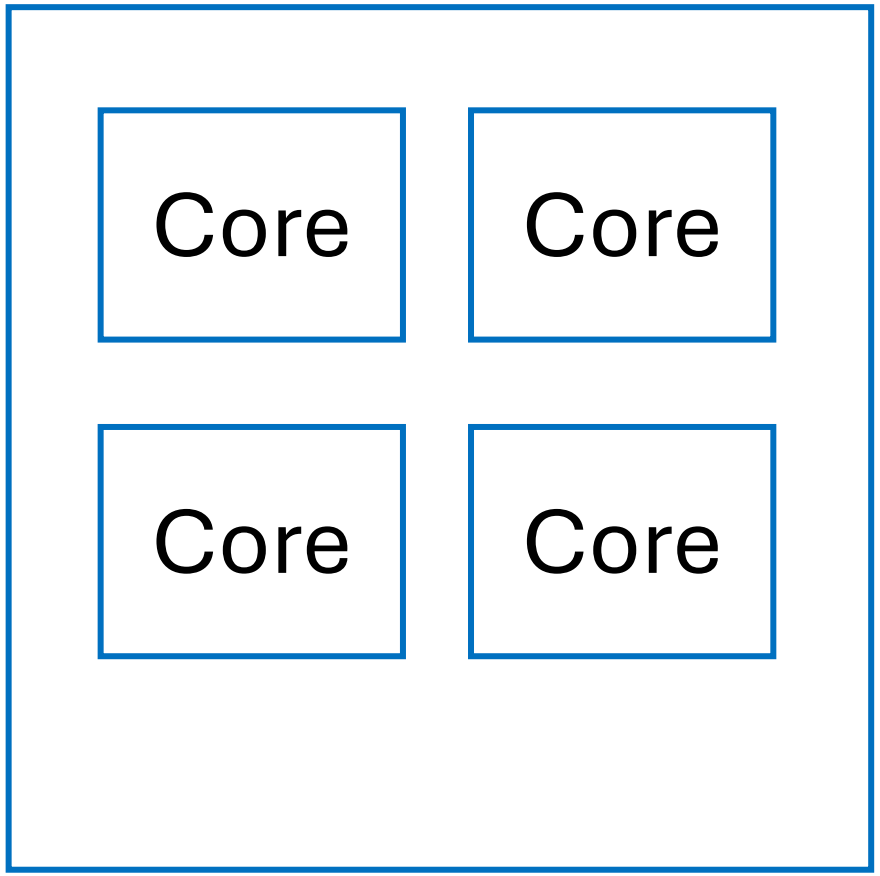


A modern chip may have four or eight independent processors called cores.

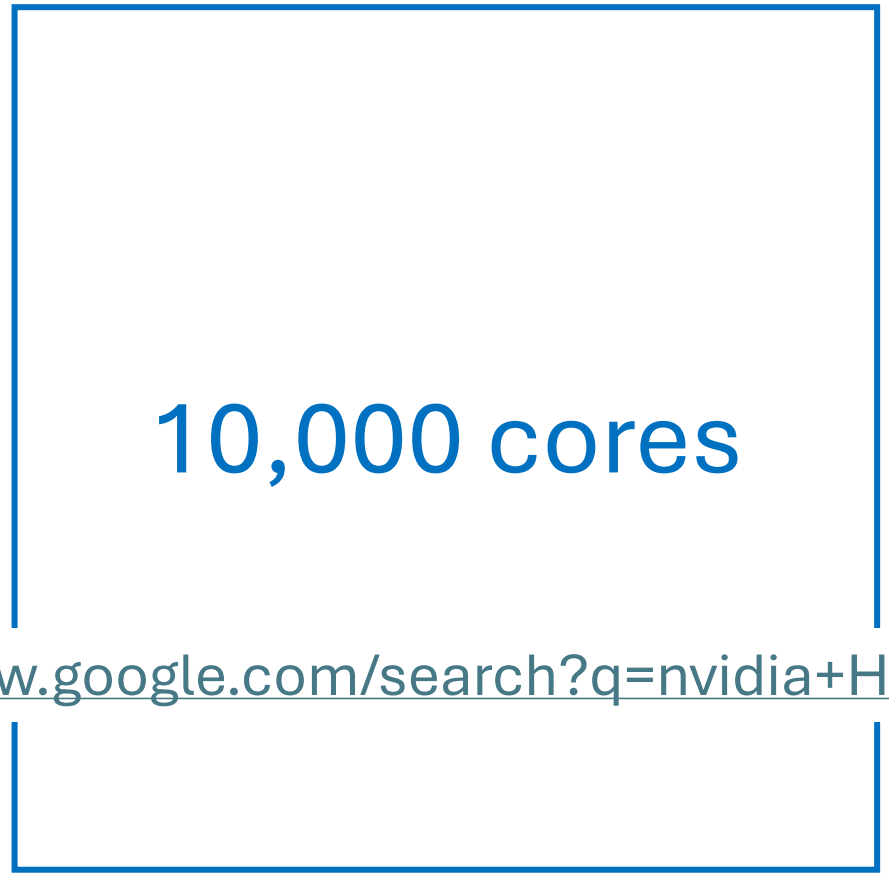


CPU from PickPik
4004 by Stelo.xyz, Pttn, or Thomas Nguyen / CC BY-SA 4.0

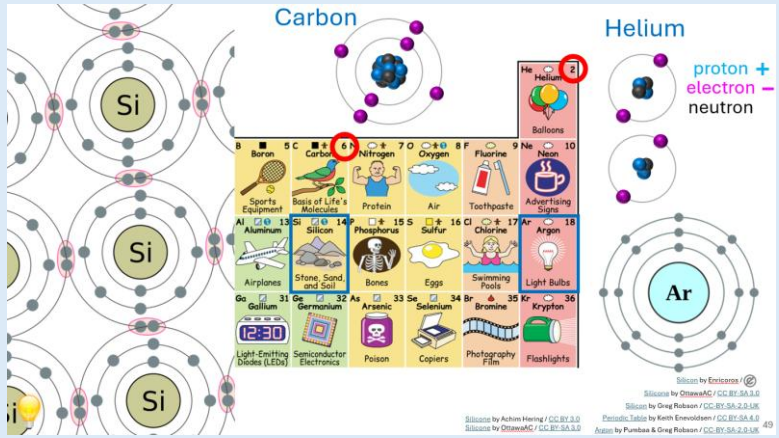
Quad-core CPU

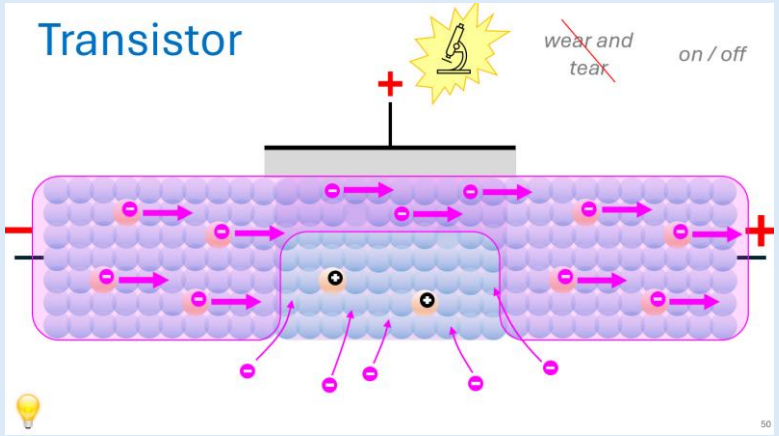


GPU

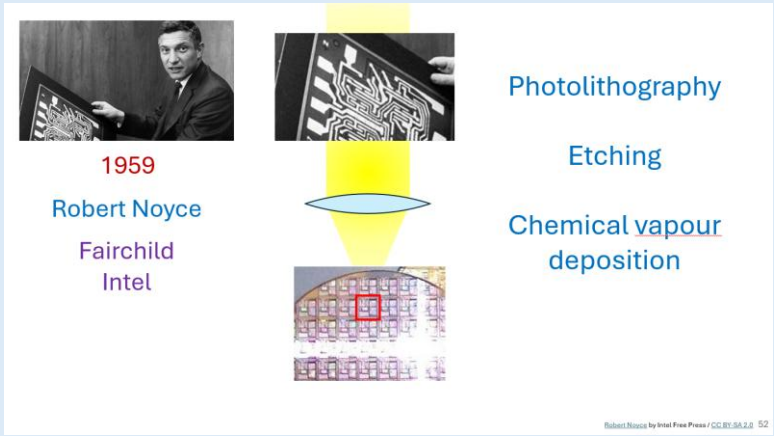


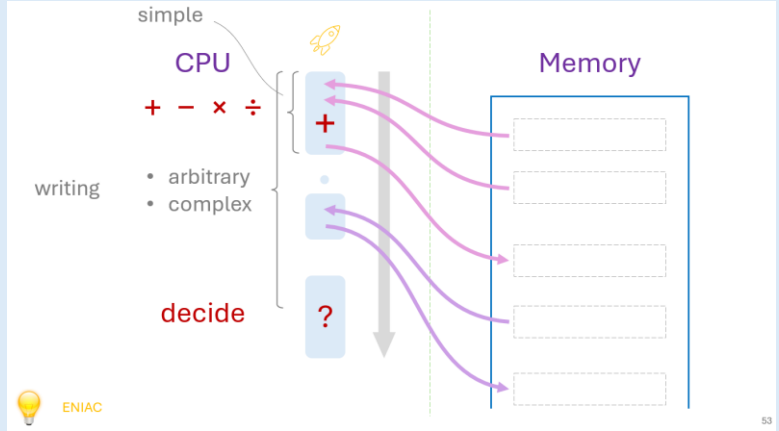
https://www.google.com/search?q=nvidia+H100

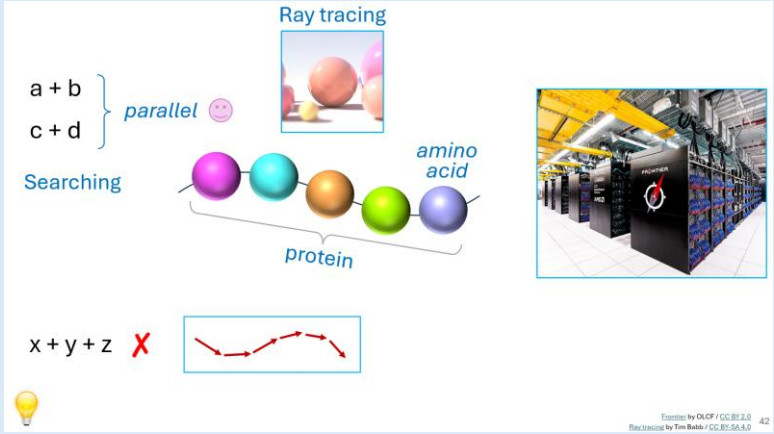

Carbon
Helium
proton +
electron −
neutron
Si
Si
Si
Ar


Transistor
wear and tear
on / off
+
−
+

Jan Czochralski
sand
1915
silicon
99.9999999%
quartz
1956
Czochralski process
crystal


1959
Robert Noyce
Fairchild
Intel
Photolithography
Etching
Chemical vapour deposition


simple
CPU
+ − × ÷
writing
• arbitrary
• complex
decide
?
Memory
ENIAC


Ray tracing
a + b
c + d
parallel
Searching
amino acid
protein
x + y + z ✗